respective organ and are, therefore, involved in their homeostatic regulation (Dworkin, 2007). Typically, information arising from these receptors is below sensory thresholds and, therefore, does not come to awareness, unless it exceeds its range of normal functioning. This definition can be seen as a bottom-up approach. In summary, both conceptualizations are required to understand the psychobiology underlying interoception. Depending on the psychological or neurophysiological model, both may have specific advantages or disadvantages. For the purposes of the current chapter, we understand 'interoception' as the processing and perception of signals arising from the inner organs (i.e., viscera), whereas we do not make a strong prediction as to whether this information is mediated by visceral circuitries only or is complemented by neural traffic in other sensory modalities.

The distinction between the inclusive and exclusive definitions of interoception has implications for conclusions concerning the neurophysiology mediating embodied processes involving interoceptive signals: While the exclusive definition allows for the attribution of an embodied process to a clear pathway of visceral-afferent neural signal transmission, the inclusive definition rests on the assumption that afferent signals from different sources are integrated at a higher cortical level, such as the insular cortex (see: Neural Correlates of Interoception). There are examples of both: On the one hand, the embodiment of time perception, which requires the higher cortical integration of afferent signals from multiple bodily sources, is a typical example for the inclusive definition of interoception (Craig, 2009). On the other hand, the enhancement of memory consolidation by post-learning stress depends on the transmission of visceral-afferent signals between the brainstem and the limbic system (McGaugh, 2000), which is an example of an embodied process based on the exclusive definition.

Structure of This Chapter

We begin by describing the neural processes underlying interoception, which are essential for the understanding of current models and assessment methods of interoception. We then discuss the most important models, followed by a description of methodological

approaches to assess interoceptive facets, as this knowledge is relevant to understand research designs and empirical findings concerning interoception and embodiment. Subsequently, we discuss different research designs, which may be used to assess specific aspects of embodiment. Finally, we present examples of the relevance of interoception and embodiment in the etiology of mental disorders.

Neural Correlates of Interoception

Receptors

The stimulation of interoceptors in visceral organs, whose activity is transmitted to brain circuitries responsible for the representation and integration of visceral-afferent signals, represents the main neurophysiological substrate of interoception. The type, function, and location of the receptor largely depend on the organ system involved. Arterial baroreceptors and cardiac (atrial) mechanoreceptors (Dworkin, 2007; Gray et al., 2007; Vaitl, 1996) are presumed to play an important role, for example, in the monitoring of the activity of the cardiovascular system. Slowly and fast adapting pulmonary stretch receptors, as well as feedback from inspiratory muscles (diaphragm, intercostal, and abdominal muscles) represent neural sources of respiratory activity (Bianchi et al., 1995; Münch et al., 2019). Gastric mechanoreceptors transmit information on stomach distension to the CNS (Schulz et al., 2017; van Dyck et al., 2016). Other organ systems that are in the focus of interoception research include the skin (perception of nonspecific skin conductance fluctuations) (Andor et al., 2008) or the urinary bladder (Avery et al., 2014; Schulz et al., 2019). Beyond neural sources of interoceptive information, also humoral pathways, including endocrine information (e.g., stress hormone level) (Schulz et al., 2013b; Schulz & Vögele, 2015) or immune system activity (Oriolo et al., 2019; Savitz & Harrison, 2018) transmit relevant information on bodily states. Hormone levels, immune cell activity, and cytokine concentration are registered via specific receptors located at cranial nerves (e.g., vagus nerve) or (for those crossing the blood–brain barrier) via receptors in the brain.

The activation patterns of different organ systems vary in terms of specific rhythm and amplitude of afferent signal transmission (Khalsa

et al., 2018). This makes it difficult to compare interoceptive signals across organ domains. To address this variability, the perception of activity originating from different organ domains is typically described as different interoceptive 'modalities'. The in-depth understanding of the organ domains and interoceptors involved in embodied processes is not only relevant for the explanation of the underlying neurophysiology; it would also be important for the development of tailored intervention techniques to enhance potentially dysfunctional embodiment, as is probably the case in mental disorders with physical symptoms (see: Relevance of Interoception for Embodiment). For example, if disembodiment symptoms in borderline personality disorder (BPD) are mainly due to deficient transmission of cardio-afferent signals (Müller et al., 2015), trainings to enhance cardiac interoception would constitute an efficient way to reduce these symptoms (Schaefer et al., 2014).

Brain Networks

Neural information can be subdivided into neural traffic originating from sympathetic and parasympathetic afferents (Craig, 2002). Sympathetic information is transmitted over the lamina1-spinothalamocortical pathway, whereas parasympathetic information is projected via cranial nerves (VII., IX., X.) to the nucleus tractus solitarius (NTS). Parts of the neural traffic from both branches are relayed in the parabrachial nucleus, before different nuclei in the hypothalamus, thalamus, and amygdalae are reached. Cortical networks mediating interoceptive information include the anterior cingulate cortex (ACC), the somatosensory/somatomotor cortex, the frontal (medial orbitofrontal, lateral) and prefrontal cortex, the insular (posterior, anterior) and the opercular cortex (Cameron, 2001; Critchley et al., 2004; Pollatos et al., 2005a, 2007). While parasympathetic afferent information is represented in the left anterior insula, the right anterior insula is responsible for representing afferent sympathetic neural traffic (Craig, 2002) (see Fig. 4.1).

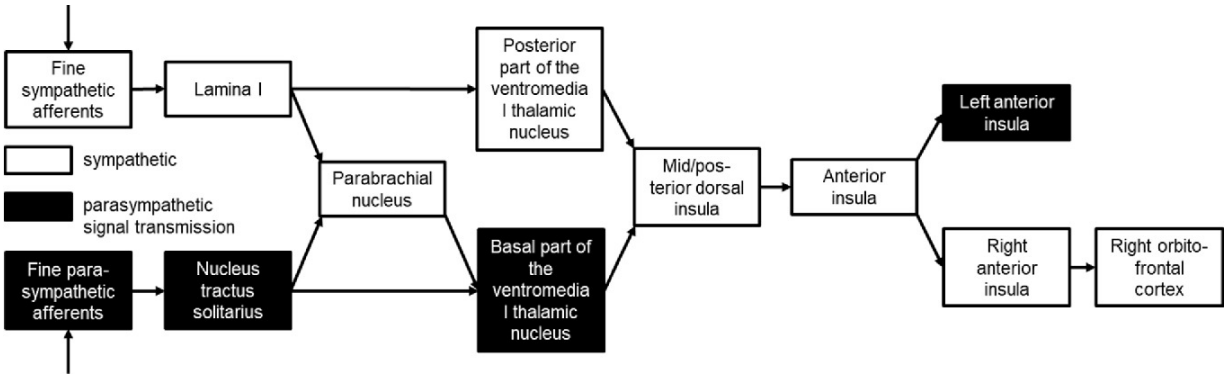


Fig. 4.1 Schematic pathways of sympathetic and parasympathetic afferent signal transmission within the interoceptive brain network.
Adapted from Craig (2002), p. 659

The Anterior Insula as Primary Center of Human Awareness

Craig (2009) described the insular cortex as the main brain region responsible for human awareness and the self. Posterior and anterior regions of the insula fulfill different roles in the representation and integration of physical and psychological states. Primary representations of visceral-afferent signals are processed in the posterior part of the insula. While neural traffic is transmitted from the posterior to the anterior part, different sources of information are integrated, including homeostatic functions (from the limbic system), environmental conditions (entorhinal and temporal cortex), hedonic conditions (nucleus accumbens and orbitofrontal cortex), and motivational, social, and cognitive states (ACC, ventromedial and dorsolateral prefrontal cortex) (Craig, 2009). All information integrated into the anterior insula form the representation of the self. This information is regularly updated with a certain frequency. Craig posited that in 'salient moments', such as the confrontation with a massive stressor, this update frequency may increase, which may be the reason for the experience of time dilatation. This example illustrates the involvement of interoceptive information for time perception, pointing toward the embodiment of time perception.

Models of Interoception

The operationalization of interoception largely depends on the underlying model, as does the specific facet of interoception. For a proper understanding of the mechanisms behind the involvement of interoception in embodied cognitions, emotions, or behavior, the consideration of the most important models of interoception is essential. For example, some mental disorders, which are associated with deficient embodiment (e.g. somatic symptom disorder/SSD), are characterized by a distinct pattern of alterations in interoceptive facets, as reflected in the increased (self-reported) tendency to focus attention on bodily signals (Flasinski et al., 2020), whereas the objectifiable accuracy in perceiving bodily signals remains unchanged (Schulz et al., 2020). Furthermore, the knowledge of potentially altered facets of interoception in mental disorders is mandatory to design tailored intervention strategies to enhance deficient embodiment (Schaefer et al., 2014). The following section summarizes the most influential models.

The Process Model of Interoception

One of the first attempts to synthesize research on interoceptive processes was presented by Vaitl (1996). A primary achievement of this model is that both physiological and psychological facets are represented and integrated. Physiological processes include receptor physiology (such as transduction and encoding), the transmission of visceral-afferent signals to the CNS, and the representation of afferent signals in the CNS. Psychological processes comprising awareness focused on interoceptive sensations as well as verbal and motor 'reports' and learning, which may, in turn, affect all levels below in a top-down manner. Some ideas were formulated in this model for the first time, which was important for the development of more recent models: First, interoception is a multifaceted construct, which can only be appropriately understood if the relationship between those (physiological and psychological) facets is known. It is likely that these facets are interconnected in regulatory circuitries. Second, a variety of methodological approaches based on psychophysiology and experimental psychology is required to reflect these facets (see Fig. 4.2). Third, processes that occur before the conscious perception of visceral sensations are to be considered 'interoceptive'. Taken

together, Vaitl's (1996) model can be seen as a framework that allows one to systematize indicators of interoception in future research and how they may be interrelated.

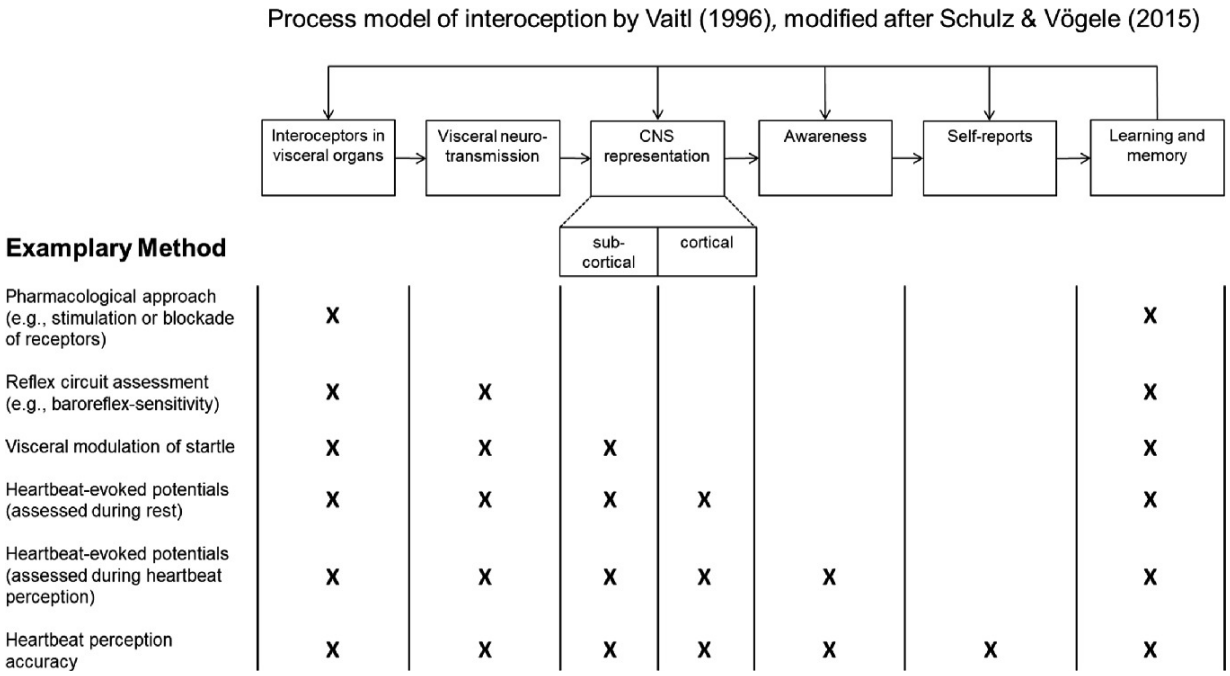


Fig. 4.2 Process model of interoception by Vaitl (1996), modified by Schulz and Vögele (2015). The table below indicates which method may be used to assess the stages as posited in the model

The Multifaceted Model

Until recently, one of the major shortcomings of interoception research was the lack of a unified terminology concerning interoceptive indicators. For example, the accuracy in heartbeat perception, which is a central approach to investigate interoception, was inconsistently named 'interoceptive awareness', 'sensibility', 'sensitivity', 'accuracy', 'ability', 'acuity', or 'performance'.

An important contribution to distinguish and systematize the most common measures is provided by the multi-faceted model by Garfinkel and coworkers (2015). The authors define 'interoceptive accuracy' (IAc) as the correspondence between physical signals (e.g., heartbeats) and their perception (for details, see methodological approaches). In contrast, self-reports of interoception represent the tendency to focus on internal bodily sensations, which is defined as 'interoceptive sensibility' (ISb). Depending on state variables, such as emotional states or stress, and on the observed population (e.g., individuals with

physical symptoms or emotional disturbances), IAc and ISb may be associated or not (Garfinkel et al., 2016b). The correspondence between both is referred to as meta-cognitive awareness of interoception, and therefore named 'interoceptive awareness' (IAw). In healthy individuals, IAc is only moderately correlated with ISb and IAw when assessed with heartbeat perception, whereas ISb and IAw are unrelated (Garfinkel et al., 2015). This has been interpreted as support for the notion that IAc represents the most basic facet of interoception.

Forkmann and colleagues (2016) proposed an extension of the Garfinkel model by including 'afferent bodily signals' as an additional level. It has to be acknowledged, however, that only one study so far has addressed heart rate as a potential indicator of 'afferent bodily signals' in this model, showing correlations between ISb and IAw, but not with IAc (Forkmann et al., 2016). Furthermore, another modification of this model concerns the inclusion of the facet 'interoceptive evaluation' (Herbert & Pollatos, 2019)—i.e., the emotional appraisal of interoceptive sensations. This facet can be assessed via ratings of arousal, valence, and anxiety (Pollatos et al., 2016) (see Fig. 4.3). Although interoceptive evaluation is clearly distinct from the other facets in theory, there is no empirical evidence so far for possible relationships with IAc, ISb, IAw or 'afferent bodily signals'. Hence, the latest theoretical model should be revised in the future depending on new findings. Nevertheless, it seems convincing that 'interoceptive evaluation' is of particular relevance for mental disorders that are characterized by the dysfunctional interpretation of physical sensations as symptoms (e.g., somatic symptom disorders, depression, anxiety disorders).

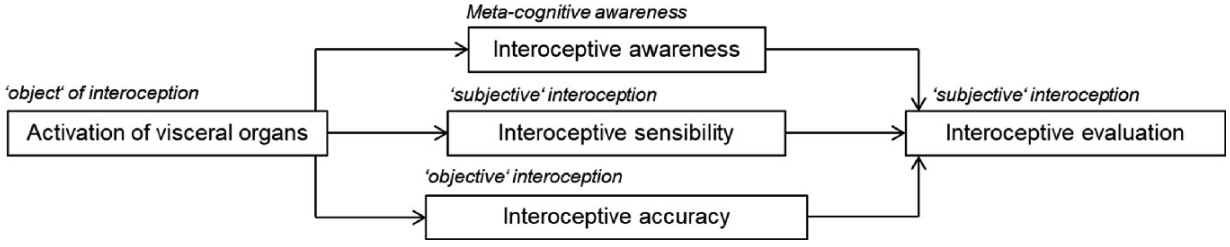


Fig. 4.3 Multifaceted model of interoception by Garfinkel et al. (2015), including modifications by Forkmann et al. (2016) and Pollatos and Herbert (2018). Please note that labeling interoceptive accuracy an 'objective' indicator of interoception is debated as this measure is based on subjective reports

The 2 × 2 Factorial Model

The conceptualization of a multifaceted model of interoception was primarily data driven, in that the low or nonexistent associations between the interoceptive facets IAc, ISb, and IAw were interpreted as support for the notion of distinguishable aspects of interoception (Garfinkel et al., 2015). Although influential, some unresolved issues remain (Murphy et al., 2019). For example, both confidence ratings in heartbeat perception tasks and scores in questionnaires, such as the Body Perception Questionnaire (BPQ) (Cabrera et al., 2018; Porges, 1993), were both seen as examples of ISb. While confidence ratings often show low to moderate correlations with IAc, associations between the BPQ and IAc are rare. To overcome this and other ambiguities (for details, see: Murphy et al., 2019), Murphy and colleagues proposed a two-factorial model: while the first factor reflects the ability dimension (i.e., 'what is measured?'), which distinguishes between 'accuracy' and 'attention', the second factor represents the measurement dimension (i.e., 'how is it measured?'), differentiating 'performance' from 'beliefs' (Murphy et al., 2020) (see Fig. 4.4).

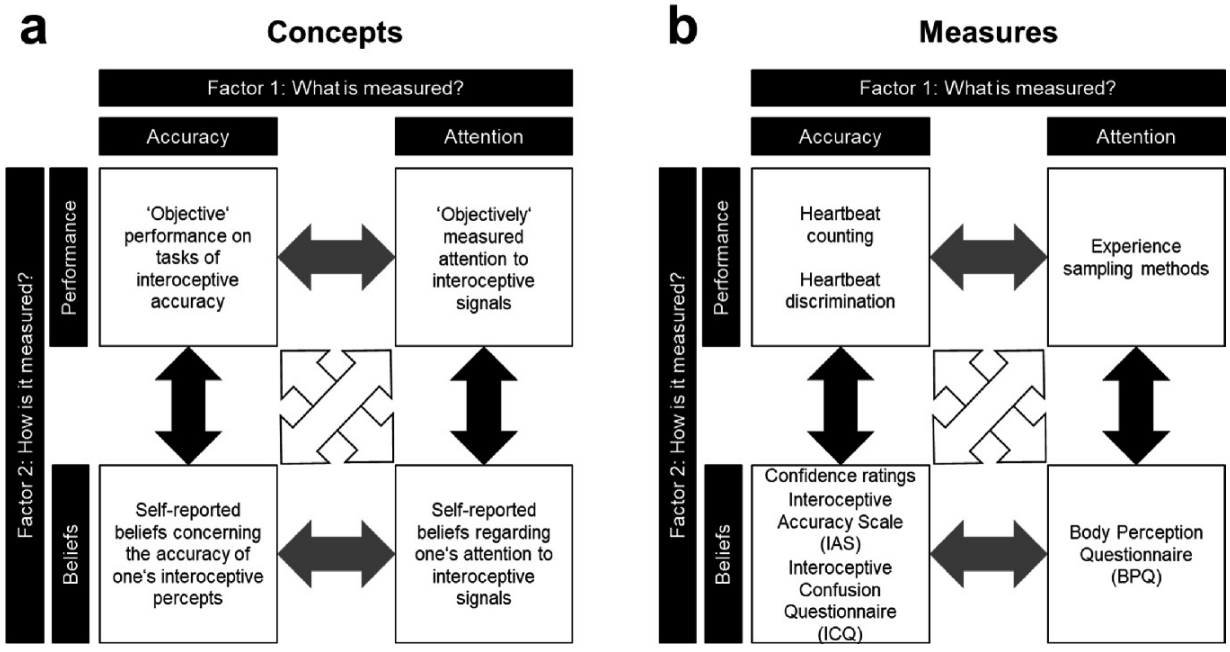


Fig. 4.4 The 2 × 2 factorial model by Murphy et al. (2019) can be seen as an extension of the multi-faceted model by Garfinkel et al. (2015). It is assumed that the correspondence between actual and perceived physical signals (i.e., accuracy) and the tendency to focus one's attention on

physical sensations (i.e., attention) can be measured both on the level of performance and beliefs (a). Scheme (b) presents possible methodological approaches to assess the 2 × 2 facets.
Adapted from Murphy et al. (2019), p. 3

In line with Garfinkel and colleagues (2015), 'accuracy' is interpreted as the degree to which interoceptive perception represents a veridical bodily state; 'attention', however, refers to the degree to which interoceptive sensations are the object of attention (Murphy et al., 2020). In this framework, IAc in heartbeat perception would be conceptualized as 'accuracy' in the ability dimension, and 'performance' in the measurement dimension, whereas confidence ratings in heartbeat perception are seen as 'accuracy' (ability) and 'beliefs' (measurement). In contrast, BPQ ratings are considered to reflect 'belief' measures of the interoceptive ability 'attention'. As IAw is defined as correspondence between 'performance' and 'beliefs', it can be separately assessed for both ability dimensions of 'accuracy' and 'attention'. This model can be seen, therefore, as an extension of the multifaceted model by Garfinkel and colleagues (2015). Importantly, the validity of this model has been supported by a number of independent studies showing that measures within one 'ability' dimension are correlated, whereas measures across 'ability' dimensions are not (Murphy et al., 2020).

Predictive Coding Model

Although the above models provide a framework for interoception and include both bottom-up and top-down regulatory circuits, they do not allow for predictions concerning how bottom-up signals and top-down regulation differentially contribute to the perception and interpretation of bodily signals. In contrast to these models, the predictive coding model takes a probabilistic view in that interoceptive signal processing involves the comparison of actually observed (perceived) and expected (simulated) bodily states (Farb et al., 2015; Seth et al., 2011). In this model, the simulation of bodily states is informed by prior experiences and the evaluation of external factors (e.g., if an individual is in a resting state, performs physical exercise, or is exposed to a stressor). Emotional responses and mental disorders that are associated with altered interoception and disturbed emotional processes (e.g., anxiety or depersonalization disorder) may result from

a discrepancy between expectation and observation, resulting in a ‘prediction error’.

Furthermore, it is likely that the individual is motivated to perform cognitive and behavioral strategies to reduce the discrepancy between expectations and observations. While the suppression of bodily sensations (e.g., by taking medications such as pain-killers, beta-blockers, anxiolytics, narcotics) is called ‘active inference’, an updating of simulated expectations (e.g., by more accurately reflecting the immediate sensation) refers to ‘perceptual inference’ (Farb et al., 2015). This allows for a classification of intervention strategies to reduce prediction errors: While pharmacological interventions are seen as examples for ‘active inference’ strategies, mindfulness techniques may have the potential to strengthen the representation of immediate bodily sensations and, therefore, should be seen as ‘perceptual inference’ strategies (see Fig. 4.5).

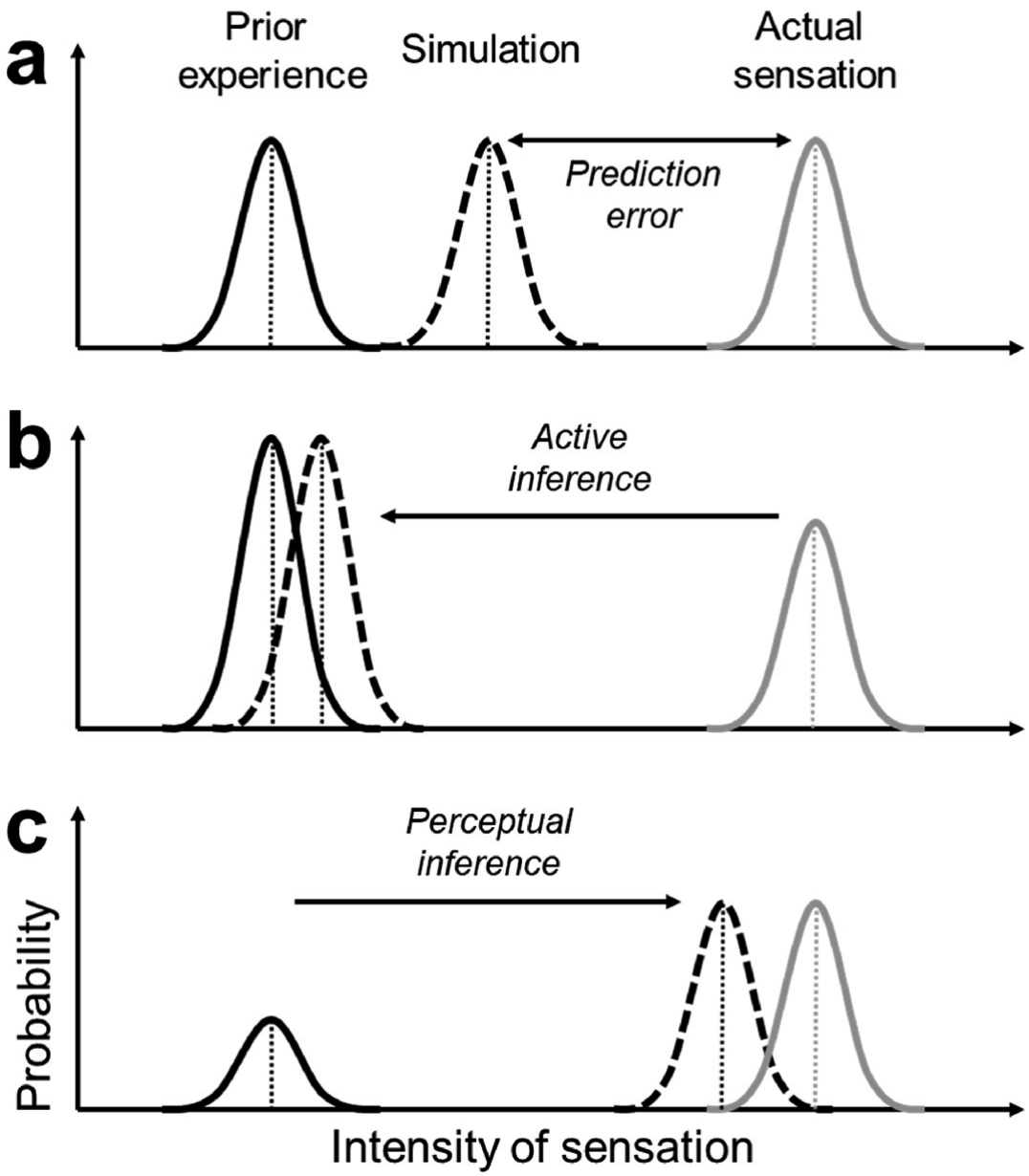


Fig. 4.5 Based on prior experience, the expected intensity of a sensation can be lower than the actual sensation in a given situation (a), such as palpitations or abdominal pain, which is considered a 'prediction error'. Active inference strategies (b) include the suppression of the actual sensations by tranquilizers, beta-blockers, or pain killers. In perceptual inferences strategies, individuals observe the current sensations and adapt their expectations to this current state.

Adapted from Farb et al. (2015), p. 9

Summary and Outlook

After years of inconsistency with regard to terminology, in recent years a number of theoretical papers have provided clearer definitions for distinguishable facets of interoception. Depending on the interoceptive

model behind each term, these definitions may vary to some degree. In case of ambiguity, we provide different explanations with reference to their respective models (see: Models of Interoception). Current definitions of the most relevant interoceptive terms are shown in Table 4.1.

Table 4.1 Overview of interoceptive terms with references to the respective model. Adapted from Farb et al. (2015), p. 3

Term	Definition	Model
Interoceptive Ability	Interoceptive dimension addressing the target of measurement: distinguishes between ***Interoceptive Accuracy*** and ***Interoceptive Attention***	2 × 2-Factorial Model[b]
Interoceptive Accuracy	'Objective' accuracy in detecting internal bodily signals, i.e. correspondence between objective bodily events, such as heartbeats, and their self-reported perception	Multi-Faceted Model[a]
	Degree how one's interoceptive perception is a representation of a veridical bodily state	2 × 2-Factorial Model[b]
Interoceptive Attention	Degree to which interoceptive sensations are object of attention	2 × 2-Factorial Model[b]
Interoceptive Awareness	Metacognitive measure of one's knowledge on his/her ***Interoceptive Accuracy***, i.e. correspondence between ***Interoceptive Accuracy*** and ***Interoceptive Sensibility***	Multi-Faceted Model[a]
	Correspondence between ***Interoceptive Performance*** and ***Interoceptive Beliefs***	2 × 2-Factorial Model[b]
Interoceptive Beliefs	One facet of factor 'What is measured?', concerns subjective ratings of either interoceptive accuracy (confidence ratings in heartbeat perception) or attention (validated questionnaires)	2 × 2-Factorial Model[b]
Interoceptive Coherence	Degree to which objectively observable interoceptive signals manifest in reportable experience[c]	
Interoceptive Performance	One facet of factor 'What is measured?', concerns putatively 'objective' assessment of either interoceptive accuracy (heartbeat perception) or attention (via experience sampling)	2 × 2-Factorial Model[b]
Interoceptive Prediction Error	Difference between predicted (expected) and perceived bodily signals	Predictive Coding Model[d]

Term	Definition	Model
Interoceptive Regulation	Degree to which one can match an interoceptive signal to his/her desired state[c]	
Interoceptive Sensibility	Subjective tendency to be focused on internal bodily sensations	Multi-Faceted Model[a]
Interoceptive Sensitivity	Minimum threshold to detect interoceptive signal strength	
Interoceptive Specificity	The ability to reject competing signals from being classified as interoceptive afferent signals, counterpart of interoceptive sensitivity[c]	

[a]Garfinkel et al. (2015); [b]Murphy et al. (2019); [c]Farb et al. (2015); [d]Seth et al. (2011)

As the following sections will show, the majority of previous research on embodiment and interoception is based on IAc (see: Relevance of Interoception for Embodiment) (Barrett et al., 2004). Nevertheless, some embodied processes, such as memory consolidation, depend on low-level CNS representation (McGaugh, 2000), whereas deficient embodiment in mental disorders is reflected in alterations in cortical CNS representation (Müller et al., 2015; Schulz et al., 2015b, 2020) or ISb (Flasinski et al., 2020). These examples illustrate that the interpretation of empirical findings necessitates an in-depth understanding of the respective interoceptive facet, and, therefore, the underlying theoretical model. We will discuss validated methods for the assessment of interoceptive facets in the next section.

Methodological Approaches

Self-reports

Based on the definition of the multifaceted model, self-reports reflect the dispositional tendency to focus on interoceptive sensations (ISb). As proposed by Garfinkel and colleagues (2015), this assessment can be performed using interoceptive questionnaires or confidence ratings in behavioral tasks, such as heartbeat perception tasks (see below). One commonly used instrument is the Body Perception Questionnaire

(BPQ) (Porges, 1993), which includes the factors ‘awareness’ (of ‘normal’ bodily sensations), and sensations associated with autonomic nervous system activity of organs above and below the diaphragm (Cabrera et al., 2018). Although some studies occasionally have shown correlations of one of these factors with other interoceptive indices (IAc) (Critchley et al., 2004; Schulz et al., 2013a), these are not consistently reported (Garfinkel et al., 2015). As the 2 × 2 factorial model considers the BPQ (‘belief’/‘attention’) and confidence ratings (‘belief’/‘accuracy’) as indicators for two separate constructs, it remains to be clarified if ‘belief’/‘accuracy’ could also be assessed using a questionnaire independent of a heartbeat perception task. The Interoceptive Accuracy Scale (IAS) was designed for this purpose and has shown good convergent and discriminant validity (Murphy et al., 2020).

Another popular instrument is the Multidimensional Assessment of Interoceptive Awareness (MAIA) questionnaire (Mehling et al., 2012, 2018). This instrument includes eight subscales labeled Noticing, Not-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting. This questionnaire, therefore, mainly focuses on interpretative facets of interoception. The MAIA conceptualizes IAw as ‘a cognitive set in which, thoughts/feelings are experienced as mental events, rather than as the self’ (Mehling, 2016), which is different from the definitions in the multi-faceted model. Abnormal patterns in the MAIA have been observed for pain-related conditions, such as lower back pain (Mehling et al., 2013) or fibromyalgia (Valenzuela-Moguillansky et al., 2017). Importantly, the MAIA scale Body Listening is understood to assess a ‘sense of an embodied self’ (Mehling et al., 2012), which may be seen as a dedicated self-reported indicator of an embodiment involving interoception.

Behavioral Tasks

The cardiovascular system. Experimental approaches to assess interoception primarily focus on the comparison of perceived and actual bodily signals. Based on the multifaceted model by Garfinkel and colleagues (2015), this correspondence is considered the operationalization for IAc. Activity of visceral organs, however, does not typically allow isolating a discrete ‘actual’ or objectifiable bodily

signal. The only exception may be a heartbeat, which can be clearly discriminated from background vascular activity. This is presumably the main reason why heartbeat perception tasks belong to the most commonly used paradigms to measure IAc. In principle, there are four popular types of heartbeat perception tasks:

(1) Heartbeat counting tasks (HCT; see Fig. 4.6a), in which the number of perceived heartbeats during silent intervals are counted and compared to those measured by heart rate monitors (e.g., electrocardiogram) (Schandry, 1981). Confidence ratings in HCT trials (Likert scale) are typically seen as an indicator of ISb in the Multi-Faceted Model by Garfinkel and colleagues (2015), and as an indicator of 'accuracy'/'beliefs' in the 2 × 2 factorial model (Murphy et al., 2019). The correspondence of IAc and ISb, such as indicated by intra-individual correlations across trials, is interpreted as an index of IAw (Forkmann et al., 2016; Garfinkel et al., 2015).

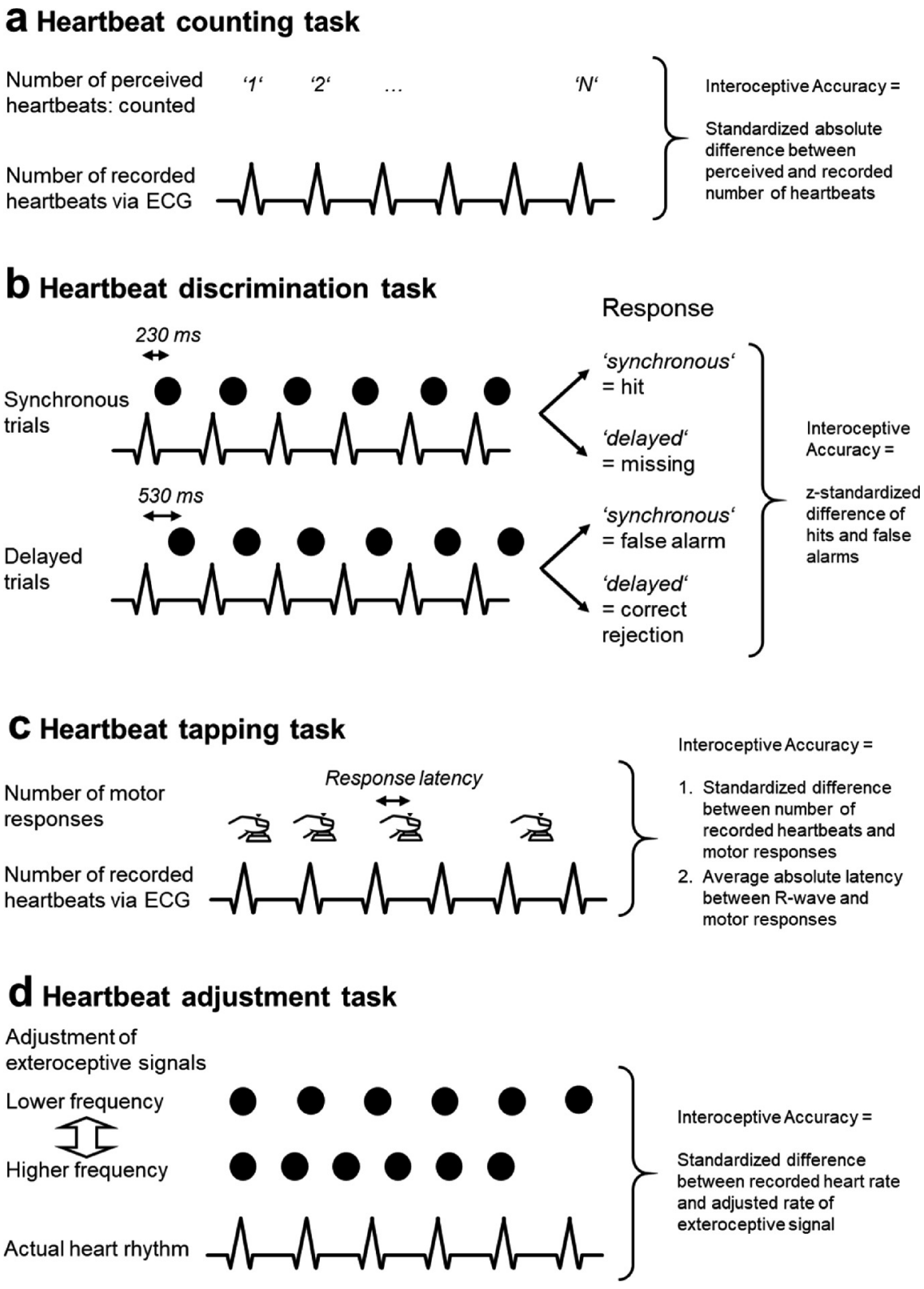


Fig. 4.6 Common heartbeat perception tasks to assess cardiac interoceptive accuracy

(2) Heartbeat discrimination tasks (HDT; see Fig. 4.6b), in which

participants are requested to determine if an exteroceptive signal (e.g., a tone, a flashing light, or a tactile stimulus) appears simultaneously or delayed to a set of one's own heartbeats (Whitehead & Drescher, 1980). Similar to HCTs, confidence ratings assessed on each trial of the HDT serve as an index of ISb or 'accuracy' / 'beliefs'. IAw is estimated using the area under the receiver operating characteristic (ROC) curve based on IAc and ISb values (Garfinkel et al., 2015).

(3) Heartbeat tapping tasks (HTT; see Fig. 4.6c), during which participants are asked to respond to every perceived heartbeat with a button press (Canales-Johnson et al., 2015; Ludwick-Rosenthal & Neufeld, 1985).

(4) In Heartbeat Adjustment Tasks (HAT; see Fig. 4.6d), participants are asked to adjust the frequency of an exteroceptive signal (e.g., metronome) to the putative frequency of their own heartbeat (i.e. heart rate) (Carroll & Whellock, 1980).

The range of methods employed in these tasks makes it unlikely that they assess exactly the same psychological construct. For example, IAc in the HCT may sometimes be associated with the ability to estimate the length of time intervals and knowledge of one's own heart rate, whereas IAc assessed by the HDT also reflects the capability for multisensory integration and a vast majority of participants only reach IAc levels around chance probability. While in some studies investigating differences and commonalities of these tasks, moderate positive correlations between IAc based on HCT and HDT were reported, others did not support this association. Notwithstanding some methodological concerns, such as non-interoceptive factors affecting IAc based on heartbeat perception, it has to be summarized that the validity of their IAc indices is supported by a number of studies, demonstrating correlations with indices reflecting gastric sensitivity (Herbert et al., 2012; van Dyck et al., 2016; Whitehead & Drescher, 1980) or with neurophysiological indicators, such as heartbeat-evoked potentials (Pollatos & Schandry, 2004), or reduced IAc in individuals with a degeneration of afferent autonomic nerves (Pauli et al., 1991).

The respiratory system. The respiratory system, with its alternation between inspiratory and expiratory phases, shows a comparable rhythmicity as the cardiovascular system, but slower in frequency. Two important differences to the cardiovascular system, however, have to be emphasized: First, there is no internal 'discrete' stimulus, like the heartbeat, which could be differentiated from background signals. Second, respiratory activity is partially regulated by both autonomic and voluntary processes. A transfer of heartbeat perception tasks into the respiratory modality is, therefore, not possible. Instead, tasks to assess IAc in the respiratory domain are based on the perception of externally presented stimuli in the form of respiratory loads (resistances in the airflow).

Another approach to quantify respiratory interoception is to assess the sensory threshold for respiratory sensations—i.e., low-intensity respiratory loads, which is defined as 'interoceptive sensitivity' (ISt). In these tasks, respiratory loads increase, but are of low intensity, and the person has to judge if the threshold was reached or not (Garfinkel et al., 2016a).

The gastrointestinal system. For the assessment of gastrointestinal interoception, again an external stimulus has to be presented, which can either be a 'natural', noninvasive stimulus, such as the ingestion of water ('water load test'/WLT), or an invasive stimulus, such as an inflating balloon inserted via a catheter into the esophagus, the stomach, or the intestine.

In WLT-based research paradigms, participants are asked to drink water from a covered container until they reach the level of satiation (Herbert et al., 2012) or satiation and fullness in a two-step process (van Dyck et al., 2016). The amount of ingested water is interpreted as an index of gastric ISt with regard to the dimensions of satiety and fullness.

Balloons inserted into the esophagus, stomach, or intestine are primarily used to evoke unpleasant or painful sensations (Horing et al., 2013), as in conditioning paradigms (Ceunen et al., 2015). Nevertheless, different levels of balloon inflation can be utilized to assess gastric or intestinal ISt. It has to be acknowledged, however, that the insertion of a catheter is a highly unpleasant event per se, without considering the potential inflation of a balloon. It is likely, therefore,

that these techniques largely interfere with the dependent variables (i.e., interoceptive indicators), as both unpleasantness and stress affect interoception.

Psychophysiological Indicators

The key neurophysiological process underlying interoception concerns the transmission of (mainly neural) signals from a peripheral organ system to the CNS, where they are represented and processed to shape the perception of visceral sensations. Psychophysiological indicators of these processes, therefore, are based on the synchronization of a psychophysiological signal from a peripheral organ (e.g., the ECG for cardiac activity) and a signal reflecting CNS activity (e.g., EEG for brain activity).

Evoked brain potentials. Afferent information from peripheral organs, such as the heart, the lungs, or the stomach, is continuously transmitted over neural pathways to interoceptive brain networks (see: Neurophysiology). For the cardiovascular system, where there is a relatively distinct 'natural' interoceptive stimulus (i.e. the heartbeat), only the passive registration of cardiovascular and electrocortical activity is required. For other organ systems, such as the lung, the stomach, the intestine, or the urinary bladder, the amplitude of variations in CNS processes by the natural rhythmicity of these organs may be too low to be registered reliably. Here, the typical approach is to present an external stimulus (e.g., respiratory occlusion) that evokes an interoceptive sensation and the related brain potential.

Heartbeat-evoked potentials (HEPs). A heartbeat evokes an electrocortical response, known as HEP, which is considered an indicator of the processing and perception of this heartbeat (Schandry & Montoya, 1996). The HEP is an event-related potential with the R-wave of the electrocardiogram (ECG) representing the 'event' (see Fig. 4.7). Between 160 (Yoris et al., 2017) and 652 ms (Petzschner et al., 2019) after the R-wave, a characteristic brain wave can be observed mainly over frontal and central areas (Schandry & Montoya, 1996), with larger amplitudes over the right hemisphere and the midline than over the left hemisphere (Pollatos & Schandry, 2004; Schulz et al., 2015a). The polarity of the HEP is mainly positive (Schandry & Montoya, 1996), but depends on the exact time window used (Schulz et

al., 2018). Given that visceral-afferent signals from the cardiovascular system are due to neural traffic from cardiac interoceptors, such as arterial baroreceptors, it is unlikely that this information is processed in cortical areas before 400 ms after the R-wave (Gray et al., 2007).

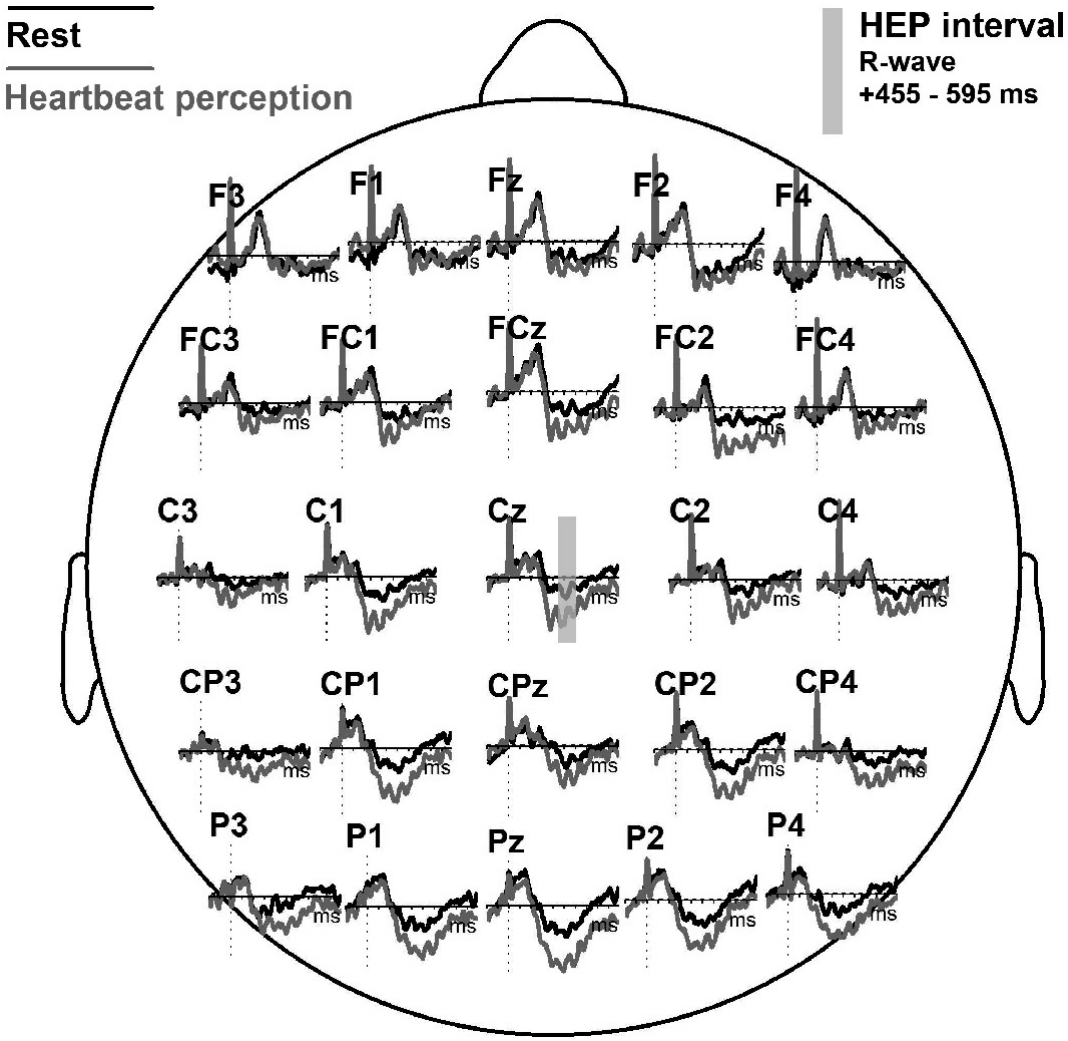


Fig. 4.7 Distribution of heartbeat-evoked potentials (HEPs) over the scalp. HEP amplitudes (i.e., positivity) are higher when performing a heartbeat counting task than during rest, potentially reflecting the attentional focus on heartbeats. The gray bar indicates the 'normal' interval, during which HEPs are evaluated

When assessed in a resting state or while performing a foreground task, the HEP amplitude is considered as the raw 'CNS representation' (see: Process Model) of visceral-afferent signals from the cardiovascular system (Gray et al., 2007; Schulz et al., 2013b, 2015a, 2018). HEPs can also be assessed while performing a heartbeat

perception task. In this case, HEP amplitudes are associated with IAc (Pollatos & Schandry, 2004), the motivation to perform in the task (Weitkunat & Schandry, 1990), and the attention focused on heartbeats (Montoya et al., 1993) (see Fig. 4.7). Furthermore, IAc training increases HEP amplitudes (Schandry & Weitkunat, 1990). HEPs are, therefore, considered to reflect the 'awareness' (Process Model) or 'attention' (2 × 2 Factorial Model) of interoception. In healthy individuals, for example, positivity of HEP amplitudes in the time window of 455–595 ms is higher when performing an HCT than at rest. This difference can be interpreted as an index of the degree of attention focused on heartbeats. In a recent study, HEPs were shown to be associated with attention focused on heartbeats (without engaging in a heartbeat perception task); this HEP modulation correlated with self-reports of autonomic nervous system perturbations (Petzschner et al., 2019). One interpretation of this finding is that HEP modulation by attention focused on heartbeats may reflect the interoceptive 'prediction error' as suggested by the Predictive Coding Model.

The involvement of interoceptive brain networks in mediating HEPs was demonstrated by dipole-localization studies. These studies suggest that important cortical generators of the HEPs are located in the ACC, the medial frontal, and the somatosensory, and the anterior insular cortex (Müller et al., 2015; Pollatos et al., 2005a).

Respiratory-related evoked potentials (RREPs). In contrast to HEPs, respiratory-related evoked potentials (RREP) require an interoceptive stimulus that is externally presented. This stimulus can consist of a respiratory load or occlusion presented during the inspiratory (Davenport et al., 1986) or expiratory phase (Hammond et al., 1999) of the respiratory cycle, while participants breathe through a mouthpiece. The resulting RREP is considered to reflect the processing and perception of this respiratory stimulus. RREPs consist of early components, such as the Nf and P1, reflecting early stages of interoceptive signal processing and stimulus characteristics, and later components (e.g., N1, P2, and P3), indicating higher order processing, including attentional processes and affective responses to interoceptive sensations (von Leupoldt et al., 2013). RREP amplitudes reflect the intensity of the respiratory load (i.e., stimulus intensity). Furthermore, late RREP components (e.g., P3) are only observed with

respiratory loads above the individual's sensory threshold and when the individual focuses their attention on respiratory sensations (Davenport et al., 2007). These examples are considered supporting evidence for the association of RREPs with the perception of respiratory sensations.

Early RREP components (Nf, P1) can be understood as indicators of 'CNS representation', whereas later components (e.g., P3) reflect 'awareness' (see: Process Model) or 'attention' (2 × 2 Factorial Model). Possible cortical generators of RREPs are located in the frontal, sensorimotor, and parietal cortices (von Leupoldt et al., 2010). In serious respiratory conditions, such as life-threatening asthma (Davenport et al., 2000), but also in people with high trait anxiety or anxiety disorders (von Leupoldt et al., 2011), alterations in RREPs have been shown, indicating abnormal neural processing of respiratory sensations.

Viscerosensory-evoked potentials (VSEPs) from the gastrointestinal system. While the presentation of respiratory occlusions may be uncommon or uncomfortable for many participants, the stimuli presented when investigating the cortical processing of interoceptive signals from the gastrointestinal system may be even more aversive. One approach is to inflate an esophageal balloon and monitor the viscerosensory-evoked potentials (VESPs) associated with this stimulus (Hobson et al., 2000). Another approach is the electrical stimulation of the esophagus (Hollerbach et al., 2000). Furthermore, intestinal stimulation by mechanical or electrical stimuli can be carried out through rectally inserted endoscopes (Hobday et al., 2000). Despite the variability in stimulation techniques and locations, all VESPs have a comparable morphology. Explanations concerning the underlying neurophysiology mainly focus on the involvement of possible (pain) nerve fibers, with especially early VESP components (e.g., N1) being mediated via myelinated Aδ fibers (Hobson et al., 2000). Neither brain networks associated with VESPs, nor the relationship of VESP components with attentional or affective processes, have been investigated in these studies. It remains debatable, therefore, if early components (e.g., N1) reflect raw 'CNS representations' and later components (e.g., P2, N2) represent 'awareness' and 'attention' (see: Process Model; 2 × 2 Factorial Model).

Cardiac and respiratory cycle effects. Visceral-afferent signals from peripheral body organ systems, such as the cardiovascular or the respiratory system, represent an important neural correlate of interoception. It is almost impossible, however, to directly assess visceral-afferent signals at a certain time index in in vivo studies in human participants, as this would require highly invasive procedures. To avoid the direct assessment of nerve activity, one alternative approach is to utilize the natural variability in visceral-afferent neural traffic. For example, across a cardiac cycle, the stimulation of cardiovascular interoceptors is not constant. The stimulation of atrial mechanoreceptors reaches its maximum before ventricular contraction, whereas arterial baroreceptors are stimulated most intensely during blood outflow after the opening of the aortic valve.

As summarized by Edwards and colleagues (2009), the pulse pressure reaches the aortic arch 90 and the carotid sinus approx. 140 ms after the cardiac R-wave, which results in the highest neural traffic of arterial baroreceptors in the systolic cardiac cycle phase at around R + 250 ms. Neural input from arterial baroreceptors in the diastolic phase is relatively constant. Interestingly, increased input from arterial baroreceptors exerts specific effects in the CNS, ranging from an inhibition of pain perception (Rau et al., 1994), reduction in cortical excitability (Rau et al., 1993), prolongation of psychomotor response times (Birren et al., 1963; Edwards et al., 2007; Schulz et al., 2009c), and modulation of reflexes (Edwards et al., 2001, 2002; Schulz et al., 2009a). Some of these findings are based on the external stimulation of arterial baroreceptors using neck suction devices, which are highly effective (Rau et al., 1992), but lack ecological validity and are invasive techniques.

An alternative approach involves the investigation of baroreceptor-modulated processes under natural conditions, during which high (i.e., systolic cardiac cycle phase) and low (i.e., diastolic cardiac cycle phase) baroreceptor stimulation can be expected (see Fig. 4.8). For example, the electromyographic eyeblink response to acoustic startle stimuli is lower when elicited during the cardiac systole (e.g., 230 ms after an R-wave) than the cardiac diastole (e.g., R + 530 ms) (Schulz et al. 2009a, b, c, 2011, 2016a). The difference in startle responses between cardiac systole and diastole is largely diminished in individuals with

degeneration of afferent autonomic nerves, and correlates with the integrity of the arterial barore lex (Schulz et al., 2009a). This effect has been named 'cardiac modulation of startle' (CMS) and can, therefore, be used to estimate the extent of baro-afferent neural feedback.

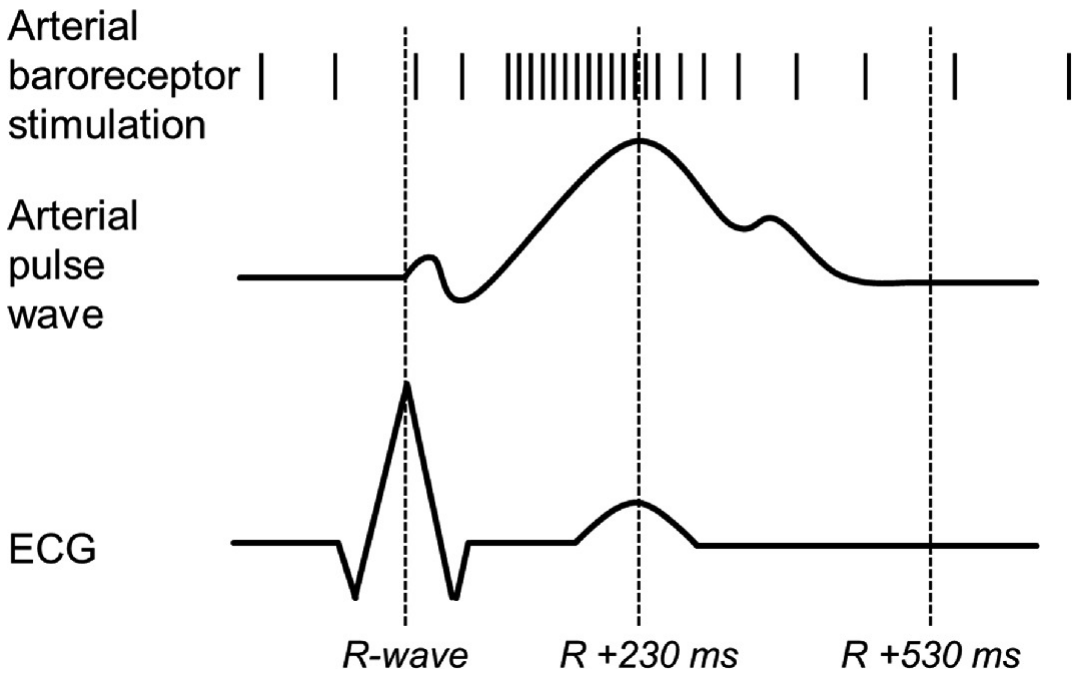


Fig. 4.8 During the early cardiac cycle phase (e.g., R-wave + 230 ms) the stimulation of arterial baroreceptors is higher than during the late cardiac cycle phase (e.g., R + 530 ms). In healthy participants, startle eyeblink responses to acoustic stimuli are lower in the early than in the late cardiac cycle phase, potentially due to higher baro-afferent neural traf ic in the early cardiac cycle phase ('cardiac modulation of startle')

The precise neural pathways of the CMS effect remain unclear though. As the largest attenuation of startle responses can be observed around 230 ms after an R-wave and occur, therefore, simultaneously with the arrival of the maximum baroreceptor input at the CNS (Edwards et al., 2009), it could be argued that the effect is due to a quick neural relay (putatively at brainstem level) without the involvement of higher limbic or cortical structures. In terms of the Process Model of interoception, this may index 'CNS representation', but (in contrast to HEPs) at sub-cortical or brainstem levels. Altered CMS and, therefore, brainstem CNS representation has been reported in individuals with depersonalization/derealization disorder (Schulz et al., 2016a), which may be associated with sympathetic hyperactivity in this population (Schulz et al., 2015b; Simeon et al., 2003).

A comparable approach could be used to estimate afferent signals from the respiratory system. Here, startle stimuli are presented at different phases within the respiratory cycle, including maximal inspiration and expiration, as well as the midpoints of the inspiration and expiration phases. An increase of startle responses at the midpoint of the expiration phase suggests that afferent neural traffic from pulmonary stretch receptors and inspiratory muscles is minimal during this respiratory cycle phase (Münch et al., 2019; Schulz et al., 2016b), which has been described as 'respiratory modulation of startle' (RMS). It is yet unclear if individuals with pulmonary dysfunction (e.g., COPD) show alterations in RMS patterns that could indicate the abnormal processing of afferent respiratory signals.

EEG/ECG single-trial covariation. While all previous approaches aim at investigating interoceptive processes, which imply the afferent transmission of neural signals from peripheral organs to the brain, there is another popular method available that may reflect the bidirectional relationship between brain and peripheral organ activity (i.e., brain–heart coupling). In the EEG/ECG single-trial covariation method, electrocortical (ERP) and heart rate responses to external stimuli (e.g., feedback in decision-making tasks) are recorded. In a correlational analysis, a negative association between the positivity around 300 ms (partially reflecting the P300 component) and the heart period (RR intervals) between 2 and 4 s after the stimulus has been shown (Mueller et al., 2010). This association has been labeled 'N300H'; it is assumed to reflect the synchronization of cortical processes and cardiovascular regulation. Due to its correlative nature, this approach cannot be used to draw conclusions on interoceptive pathways only. Instead, it is likely that this method reflects the bi-directional regulation and integration of afferent and efferent signals exchanged between cortical networks and autonomic circuitries. Reduced brain–heart coupling indexed by the N300H has been observed in carriers of short alleles of the serotonin transporter polymorphism (5-HTTLPR), which may express lower levels of 5-HT transporters (Mueller et al., 2013). In contrast, a higher brain–heart coupling has been described in individuals with panic disorder (Mueller et al., 2014). One could argue, therefore, that alterations in regulatory circuits, which process afferent and efferent neural signals

transmitted between the brain and the cardiovascular system, constitute a pathophysiological mechanism that contributes to the etiology of anxiety disorders or depression (mediated via serotonergic pathways).

Results from source localization studies suggest that the N300H is mediated by the ACC and the anterior insula (Panitz et al., 2013), which represent two of the most important cortical structures involved in interoception. This, in turn, suggests that brain networks important for interoception are involved in the afferent pathway of the bidirectional brain–heart communication reflected by this method. In contrast with the previous methods, the EEG/ECG single-trial covariation method is suitable to study embodied responses to feedback in decision-making paradigms, whereas it is likely that interoceptive signals are integrated in these responses.

Research Designs

The core assumption underlying studies addressing embodiment through interoceptive methods is that afferent signals and their processing in the CNS are integrated into psychological processes, such as emotion, decision-making, or consciousness. A principle challenge of all methodological approaches is, therefore, to assess the foreground process (e.g., emotional experience) and the (background) interoceptive process simultaneously and without interference between both.

Correlational Approaches

One way to overcome these challenges is to assess interoception and the respective foreground process (e.g., emotional experience, emotion regulation, emotion recognition) separately. To demonstrate possible associations between both, mainly correlation (Barrett et al., 2004; Füstös et al., 2013; Pollatos et al., 2015) or regression analyses are used (Dunn et al., 2010; Grynberg & Pollatos, 2015). Another statistical approach is the separation of study samples into individuals with low versus high IAc either by an external criterion (e.g., IAc score of 0.85) (Herbert et al., 2010; Herbert et al., 2007a; Werner et al., 2013), a data-driven approach if a bimodal distribution is present (Herbert et al.,

2007b; Pollatos et al., 2005b), or a median-split (Garfinkel et al., 2015). The latter approach is primarily reported in earlier papers.

Both embodiment and interoception have state and trait components (Wittkamp et al., 2018). For example, mental disorders characterized by altered embodiment, such as depression, are associated with reduced trait IAc and CNS representation of interoceptive signals (Terhaar et al., 2012); however, IAc is also change-sensitive (i.e. a state), as it may be affected by stress (Schulz et al., 2013a) or can be improved through training procedures (Schenk et al., 2020). One could argue, therefore, that due to this change-sensitivity, the contribution of interoception to embodiment also depends on psychological states. A principal shortcoming of the correlational approach is that interoception and embodiment are often not assessed simultaneously, but sequentially (e.g., using two different paradigms). Even if the experimental paradigm is identical, a potential correlation should be interpreted with caution, as it remains unclear if interoceptive signal processing was actually identical at the moment of performing the respective task to assess the embodied process. Instead, a correlation may predominantly indicate an association of the trait components of interoception and embodiment. Still, an advantage of this approach is that multiple indicators of interoception and multiple embodied processes can be assessed in an exploratory fashion, which may guide future hypotheses in experimental designs.

Experimental Designs

If one aims at drawing conclusions on causal relationships, it is mandatory to implement an experimental manipulation in at least one out of two or more groups with a random assignment of participants. The principle idea behind experimental designs is that the concurrent change of physiological activity and a psychological process (such as emotional experience, decision-making or time perception) reflects its embodiment, as afferent information on this physiological activity is integrated into the psychological process. This interpretation, however, is only reasonable (1) if it is possible to isolate the change in physiological activity and (2) if no other cognitive or brain mechanism is a side effect of this manipulation. For example, the presentation of an acute laboratory stressor after the learning phase in a memory

paradigm facilitates declarative memory (Roozendaal, 2002). While the stressor can elicit a physiological change (e.g., increased sympathetic arousal, release of cortisol), this finding should not be interpreted to support the embodiment of memory formation per se, as the physiological changes are not isolated from brain processes. Rather, the effect might be due to the activation of limbic structures in the brain (which would not be entirely consistent with an embodied process) or the activation of the sympathetic nervous system and the HPA axis (which may qualify as an embodied process). Both are necessary to mediate the stress-enhancing effect on declarative memory (i.e., visceral-afferent neural signals are essential) (McGaugh, 2000), which can be seen as supporting the thesis that memory formation represents an embodied process.

Psychophysiological processes as an independent variable. Peripheral physiological activity can be manipulated, for example, by pharmacological designs or by nerve stimulation (e.g., transcutaneous vagal nerve stimulation/'tVNS'). The 'classical' experiment by Schachter and Singer (1962) represents one popular example. In this study, participants received an infusion of either epinephrine or sodium chloride, were informed about the true side effects of this infusion or not, and were exposed to a social encounter to provoke anger or not. One key finding of this experiment was that participants who received epinephrine, were not informed of its side effects and were exposed to the anger-evoking condition interpreted their physiological arousal as 'anger', as they did not have alternative explanations for it (i.e., possible side effects). One strength of this experiment is that epinephrine effects are limited to the peripheral branch of the sympathetic nervous system, as it does not cross the blood–brain barrier. This was one of the first experiments to demonstrate the embodiment of emotional experience.

It needs to be acknowledged, however, that it is mandatory to assess indicators of physiological activity (e.g., change in heart rate and blood pressure) to draw conclusions involving interoception. Hence, later studies used more complex pharmacological designs. For example, Moor and colleagues (2005) applied two placebo-controlled pharmacological interventions in a male sample to induce activation (epinephrine) and deactivation (esmolol) of β1-adrenergic receptors,

as well as activation (norepinephrine) and deactivation (sodium nitroprusside) of α1-adrenergic receptors. The aim of this study was to investigate the potential effects of afferent cardiac signals evoked by β1- and α1-adrenergic arousal on declarative memory formation. The β1-adrenergic stimulation increased IAc, but increased declarative memory for arousing pictures only, whereas the α1-adrenergic stimulation did not affect IAc, but induced global enhancement of declarative memory. This effect was potentially due to the higher baro-afferent neural traffic caused by peripheral vasoconstriction, which may not be sufficient to increase IAc. Nevertheless, this is another indicator that memory formation represents an embodied process, as afferent signals from the cardiovascular system may enhance declarative memory.

Other strategies for the active modulation of physiological parameters include nerve stimulation, which can be performed transcutaneously, and, therefore, non-invasively. Although an application of tVNS in embodiment research is yet rare, its vasodilating effects and the subsequent decrease of baro-afferent signal transmission could be used as a potential paradigm when conclusions on causality are envisaged (Groves & Brown, 2005). In contrast to a pharmacological design, however, a tVNS protocol would make it more difficult to separate the effects of peripheral physiological activity and brain activity on a psychological process, as vagal nerve stimulation has the potential to affect signal transmission in the entire central autonomic network (e.g., brainstem, limbic system, prefrontal cortex) (Thayer & Lane, 2009).

As an alternative to active manipulation of peripheral physiological processes, one could also investigate psychological processes depending on natural variability in physiological activity, such as can be expected in the rhythmicity of the cardiac or respiratory cycle. The cardiac cycle, for example, can be divided into the systolic phase, during which the ventricular contraction and the opening of the aortic valve cause the blood outflow, versus not. This natural variability can be used for interoception research in that stimuli are presented in the cardiac systole (e.g., period of 100–300 ms after the R-wave) and diastole (e.g., R-wave + 300 ms) to compare two conditions of high and low stimulation of arterial baroreceptors. Differences between the

cardiac systole and diastole have been demonstrated for pain perception (Edwards et al., 2001, 2002), psychomotor response times (Edwards et al., 2007; Schulz et al., 2009c), startle response magnitudes (Schulz et al. 2009b, c, 2011, 2016a, 2019), visual perception (Pramme et al., 2014, 2016), memory for short sets of digits (Quelhas Martins et al., 2014) or emotional faces (Pfeifer et al., 2017), and attentional engagement in emotional stimuli (Azevedo et al., 2018).

Likewise, afferent signals from pulmonary stretch receptors and inspiratory muscles show a natural variation across the respiratory cycle. Here, psychomotor response times (Buchsbaum & Callaway, 1965; Münch et al., 2019), visual perception (Callaway & Buchsbaum, 1965), and startle response magnitudes (Schulz et al., 2016b) are affected by the respiratory cycle. These processes could be considered 'embodied', as different afferent information may affect their respective indicators. Nevertheless, these approaches do not reflect cardiac or respiratory interoception per se, but neural traffic, which plays an important role in interoception in the respective organ domain. One disadvantage of the natural variation approach might be that it is unclear if variability in peripheral physiological rhythmicity depends on brain processes, which control and synchronize this rhythmicity. This assumption is, for example, supported by evidence showing a distribution of reaction times across the cardiac cycle with a frequency within the EEG alpha band, which suggests synchronization between the brain and cardiac processes (Wölk & Velden, 1987).

Psychophysiological processes as a dependent variable. Variations in peripheral physiological activity can serve as the dependent variable, dependent on psychological processes. An example for this direction of causality is the EEC/ECG single-trial covariation method, as ERPs and changes in heart rate are observed in response to positive and negative feedback in a decision-making paradigm (Mueller et al., 2010, 2013, 2014; Panitz et al., 2013). One may argue that a broad bandwidth of peripheral physiological responses is observed in almost all psychological processes, including emotion, cognition, or executive functions, while changes in peripheral physiology do not necessarily indicate that this process requires interoceptive signal processing as a facet of embodiment. However, the N300H, as a primary index of this method, reflects the synchronization

between brain and heart processes as a correlative relationship. Moreover, as brain areas involved in interoceptive signal processing, such as the anterior insula and the ACC, seem to be involved in the N300H (Panitz et al., 2013), it is likely that this index reflects the integration of afferent and efferent signal transmission on the brain-body axis in regulatory circuits. Interoceptive signal transmission, therefore, may be essential for the N300H. A potential disadvantage of all experimental designs is that there has to be a justified a priori assumption, in which interoceptive signal and facet may be involved in an embodied process.

Recursive designs. Interoception implies the processing and perception of afferent signals from visceral organs (Schulz & Vögele, 2015). There are some psychological processes, such as emotion and stress, which are characterized by changes in efferent signal transmission from the brain to visceral organs, including the activation of the sympathetic nervous system or the release of stress hormones. As changes in the activity of visceral organs can again be perceived and could, in turn, elicit the generation of emotions and stress (Barrett et al., 2004; Herbert et al., 2010; Schenk et al., 2020; Werner et al., 2013), afferent (i.e., interoception) and efferent signal transmission (i.e., emotion and stress) between the brain and visceral organs can be construed as a recursive loop. Previous research is mainly based on correlative approaches, which do not allow for the disentangling of the causal sequence between afferent and efferent signals. To differentiate causes and consequences in recursive designs, it is essential to apply different methods to manipulate afferent and efferent signal transmission. If, for example, a laboratory stress test results in increases in self-reported anxiety only, but also increases self-reported anger after a training to enhance interoception, it can be concluded that the stronger perception of visceral activation after the training was responsible for this effect.

Relevance of Interoception for Embodiment

Based on these models, methods, and research designs, many studies have shown that interoceptive signal processing is integrated into emotional, cognitive, attentional, and behavioral processes. This

evidence supports the notion that these processes are 'embodied'. This embodiment is not limited to interoceptive signal processing, but also includes afferent signals from the proprioceptive system. Also, the elicitation of peripheral physiological changes (and, therefore, efferent signal transmission) can indicate the embodiment of the respective process. It is likely, for example, that an embodied process, such as body ownership or emotional experience, is reflected by a complex integration of afferent and efferent signals between the brain and the body in multiple sensory modalities. In the next section, we will give some pertinent examples demonstrating the involvement of interoceptive signal processing for embodied psychological processes.

Body Ownership

Body ownership is typically assessed by creating body illusions, such as the 'rubber hand illusion' (RHI). In this paradigm, a concurrent tactile stimulation of one's own hand (which is covered) and a rubber hand within the visual field of the participant induces a false multisensory integration of somatosensory and visual stimuli, which results in the experience that the rubber hand is part of one's own body. Susceptibility for the RHI as a false body representation seems to be relatively stable across time, and is considered, therefore, a trait (Bekrater-Bodmann et al., 2012). One main assumption underlying this paradigm is that the stronger the multisensory integration of interoceptive, exteroceptive, and proprioceptive information (e.g., in neural networks, such as the anterior insula), the more accurate is the body representation and, therefore, the susceptibility for body illusions (Crucianelli et al., 2018; Suzuki et al., 2013; Tsakiris et al., 2011). Although interoceptive signals may not be crucial for the integration of somatosensory and visual information, it could be argued that the adequate processing of interoceptive stimuli is a necessary factor for accurate body representation. In line with this assumption, high IAc correlates with low susceptibility for the RHI (Tsakiris et al., 2011), although a more recent study could not replicate this finding (Crucianelli et al., 2018). A conclusion to be drawn from this evidence is that interoceptive information represents one important factor for body representation, complementing somatosensory, proprioceptive, and visual information.

Embodiment in Emotion

There is a long tradition of models on interoceptive signals to be relevant for the genesis of emotions. While early concepts, such as the James–Lange theory of emotion, see changes in peripheral physiology as an equivalent of an emotion (James, 1884; Lange, 1887), later approaches suggest that physiological arousal plus the interpretation of this arousal is required for the genesis of an emotion (Schachter & Singer, 1962). Consequently, the earliest studies on cardiac IAc primarily focused on emotional experience (Schandry, 1981). Cardiac IAc is positively correlated with emotional experience, indicated by self-reports of arousal focus (Barrett et al., 2004), state anxiety (Schandry, 1981), and P300 responses to affective pictures (Pollatos et al., 2005b). IAc and emotional experience are reduced in individuals with an injury of the spinal cord (Montoya & Schandry, 1994). The same positive correlation can be observed between cardiac IAc and emotion regulation in response to affective picture presentation (indicated by the self-reported strategy 'downregulation of arousal') (Füstös et al., 2013) and as a trait measure as assessed with the Emotion Regulation Questionnaire (Pollatos et al., 2015).

Furthermore, cardiac IAc positively correlates with self-reported reappraisal and suppression strategies after being exposed to a social exclusion paradigm (Pollatos et al., 2015). These findings suggest that higher IAc is associated with stronger emotional experiences, while both seem to be required to develop adequate emotion regulation strategies, especially to cope with social encounters. Current models see interoceptive signal processing as an important, but not a mandatory factor, for emotion genesis. It is generally assumed that interoceptive signals reach 'first-order' central structures, such as dorsal pontine areas, the anterior insula, and the somatosensory cortex (Critchley et al., 2001), which are associated with emotional experience (Wiens, 2005). In a 'second order' of central representation of interoceptive signals, structures such as the ACC integrate these genuine interoceptive signals and other sources of bodily information, such as somatosensory feedback (Critchley et al., 2001). Emotional experience may thus be the consequence of integrating interoceptive signals and other information on bodily states, as well as paying attention to these processes (Schulz, 2015; Wiens, 2005).

Embodiment in Intuitive Decision-Making

As summarized elsewhere (Schulz, 2015), the influential somatic marker hypothesis by Damasio (1994) postulates that interoceptive signals are regularly integrated into processes of decision-making. It is assumed that in every context in which intuitive decisions are expected to be taken, the outcomes of possible action alternatives are anticipated. This anticipation produces a specific visceral response, which is integrated into the affective responses to the expected outcome. These responses, transmitted over interoceptive circuitries, are called 'somatic markers'. Taken together, Damasio hypothesized that these 'somatic markers' shape intuitive decision-making. The neural structure assumed to be responsible for the integration and evaluation of somatic markers is the ventromedial prefrontal cortex (VMPFC) (Bechara et al., 2000).

There is a lot of empirical evidence supporting the somatic marker theory. In experimental research, intuitive decision-making is assessed through specific paradigms, such as the Iowa Gambling Task (Bechara et al., 1994). Performance in this task has been shown to be positively associated with cardiac IAc (Werner et al., 2009), although other studies could not replicate this finding (Wölk et al., 2014). Follow-up studies suggest that this inconsistency may be due to the relationship between IAc and decision-making being moderated by anticipatory interoceptive signals favoring either advantageous or disadvantageous choices (Dunn et al., 2010). Furthermore, the entire method of EEG/ECG single-trial covariation is based on the bidirectional communication between the brain and cardiac processes associated with feedback responses in decision-making paradigms (Mueller et al., 2010), suggesting that interoceptive signals are integrated into the process of decision-making.

Embodiment in Consciousness and Time Perception

As stated previously, afferent information from the body is integrated into the anterior insula to shape the representation of the self. The update frequency of this information (which may be affected by 'salient' moments, such as intense stressors) is responsible for time perception (Craig, 2009). Several studies on interoceptive processes have investigated this notion. Time perception is typically assessed by

asking participants either to estimate the number of seconds of a stimulus (e.g., emotional movie clip) (Pollatos et al., 2014) or to reproduce the length of an auditory stimulus while being distracted by giving verbal numerical responses (to mitigate the possibility of counting seconds) (Meissner & Wittmann, 2011; Teghil et al., 2019). Using correlative approaches, both high IAc and IAw are positively associated with higher time perception accuracy (Meissner & Wittmann, 2011; Teghil et al., 2019).

A more complex picture emerges, though, when the attentional focus is experimentally manipulated toward interoceptive or exteroceptive sensations in that an interoceptive focus induces a perceived (retrospective) time dilation for fearful movies, but a time expansion for amusing movies (Pollatos et al., 2014). These findings are in line with Craig's assumptions (Craig, 2009): for neutral stimuli, precise time perception accuracy and high IAc/IAw suggest that high activity and connectivity in overlapping brain networks are essential for both processes. Notwithstanding, fearful stimuli are considered more 'salient', which may cause time dilation. Furthermore, the involvement of the anterior insula for time perception has been supported by neuro-imaging studies (Tomasi et al., 2015).

A possible association between IAc in the HCT and time estimation accuracy is debated in the literature. On the one hand, a positive relationship may indicate that interoceptive signal processing is required to shape consciousness in general and the perception of time in particular (Craig, 2009). On the other hand, this relationship may be a methodological artifact in that many participants tend to count seconds instead of heartbeats when performing the HCT (Desmedt et al., 2018; Murphy et al., 2018b; Ring et al., 2015). While this controversy highlights the need for standardized guidelines in how heartbeat counting tasks should be carried out (e.g., instructions to count and not to estimate heartbeats), there are typically low correlations of approx. $r = 0.16$ (Murphy et al., 2018a), or lower (Murphy et al., 2020).

Disembodiment in Mental Disorders

Several mental disorders can be characterized by potentially distorted embodiment. Depersonalization-/derealization disorder (DPD) and, to some extent, also BPD and post-traumatic stress disorder, are

associated with feelings of being detached from one's own body. Major depressive disorder, SSD, and panic disorder involve symptoms of an uncontrollable (over-)activity of the autonomic nervous system. As these mental disorders are associated with alterations in interoceptive signal processing, one could argue that dysfunctional interoception plays a role in the generation of disembodiment symptoms.

Importantly, specific alterations in interoceptive signal processing (e.g., CNS representation, IAc, ISb) observed in mental disorders may account for the specificity of disembodiment symptoms. For example, DPD patients showed a reduced sensitivity of HEPs for attention focused on heartbeats (Schulz et al., 2015b), potentially reflecting impaired attention focusing toward bodily sensations, which may be responsible for feelings of disembodiment. In contrast, individuals with a high number of SSD symptoms showed increased HEP sensitivity for attention focused on heartbeats, but normal IAc (Schulz et al., 2020). This finding suggests that SSD is characterized by an overflow of attentional resources toward bodily sensations, which turn minor bodily changes into physical symptoms.

A proper understanding of the precise dysfunction in interoceptive signal processing in mental disorders could inform the development of tailored intervention techniques for the reduction of disembodiment symptoms, such as perceptual learning, neurofeedback, and vagus nerve or brain stimulation. Preliminary findings on a reduction of symptoms distress in SSD after heartbeat perception training (Schaefer et al., 2014) demonstrate the potential of these approaches to normalize potentially distorted embodiment.

Conclusions

This chapter provides an overview of the terminology, models, and methods of interoception research. It provides a description of important neurophysiological foundations and introduces relevant research designs on interoceptive approaches addressing embodiment. Finally, many examples were summarized to illustrate the embodiment of relevant psychological processes by demonstrating their relationship with interoceptive signal processing. In summary, interoception constitutes a source of information in one sensory

modality, which may be central for embodied cognitions and behaviors. Nevertheless, it remains for future research to clarify if some of the embodied processes discussed in this chapter may specifically rely on the integration of interoceptive signals, whereas other sensory signals from the body, such as proprioceptive or somatosensory signals, are less important. To get a complete picture of embodiment, future studies and conceptual papers should address the relationship between different sources of sensory signals and bodily responses associated with affective, cognitive, and behavioral processes.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_5

5. Metaphorical Embodiment

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Abstract
The human body has historically been viewed as a natural, purely biological entity that is mostly separate from the mind. However, much work in embodied cognition has revealed the significant extent to which people's knowledge and experience of their bodies are recruited in a wide range of abstract thinking abilities, primarily through the mechanism of metaphor. Bodily experiences serve as the source domains to better understand less structured, and typically more abstract, target domains (e.g., LIFE IS A JOURNEY in which bodily experiences associated with journeys are mapped to better structure our understanding of life). The present chapter explores the possibility that many source domains arising from bodily experiences may themselves be inherently metaphorical. I present a variety of examples from cognitive linguistics, psychology, and medical anthropology to show how varied bodily experiences are likely understood in symbolic and metaphorical terms. Following this, I discuss several remaining questions regarding the claim that bodily experience is inherently metaphorical (i.e., the "metaphorical embodiment hypothesis"). Finally, I discuss several implications of this metaphorical embodiment hypothesis for our theoretical understanding of metaphor, embodiment, and human cognition.

Keywords Bodily experience – Cognitive linguistics – Embodiment – Metaphor – Metaphorical embodiment hypothesis – Psycholinguistics

The term “embodiment” has several meanings referring, at the very least, to the biological/neural substance that constitutes the human body, our unconscious cognitive abilities that are grounded in bodily sensations and actions, and our subjective, phenomenological experiences of the body given our internal sensations and interactions with the physical world (Gibbs, 2006; Lakoff & Johnson, 1999). We think of embodiment, more generally, in mostly physical ways. Our bodies do not seem to be abstract entities, but feel real, and have substance, weight, length, and volume. My body has bones, blood, guts, cells, DNA, which self-organize to enable me to breathe, eat, defecate, bleed, sweat, feel pain, have nausea, and move about in the world in complex, adaptive ways.

To suggest that the human body, and our experiences of embodiment, may be metaphorical seems absurd in the face of these literal, physical realities. Metaphor is, in many scholars’ view, primarily a cognitive activity that enables individuals to make sense of abstract ideas and events in terms of more familiar domains of knowledge and experience. For example, when thinking of one’s life as a journey, we come to better understand aspects of life given our diverse physical experiences of journeys. Although there is now an abundance of empirical evidence in favor of the claim that abstract thinking is highly metaphorical (Gibbs, 1994, 2006, 2017), the bodily source domains (e.g., journeys) that provide the experiential grounding for metaphor are assumed to be inherently non-metaphorical.

My argument in this chapter is that the human body is often experienced and understood through symbolic means, particularly via metaphor. Consider, for example, your bodily experience of feeling very tired or fatigued. When I am tired from a long day of mental and physical exertion, I feel this deeply within my muscles and bones, sometimes to the point of my no longer being able to stand and walk about. All I wish to do is lay down and do nothing. Feeling tired is an all-over bodily ache that only extended rest can cure.

There are many people, however, who feel tired all the time, no matter how much rest they have had. Many of these individuals have been diagnosed as having “chronic fatigue syndrome” (CFS), which is defined as “a complicated disorder characterized by extreme ***fatigue***

that can't be explained by any underlying medical condition. The ***fatigue*** may worsen with physical or mental activity, but doesn't improve with rest."[1] Chronic fatigue syndrome is a controversial disorder given that it likely arises from a complex set of factors. People suffering from CFS do not simply describe their symptoms in purely literal terms, such as saying "I am always tired" or "I am continually fatigued" but, instead, talk about their bodily experience using metaphors. Consider three people with CFS who responded to the question "What does it feel like to have CFS?".[2]

> "Chronic fatigue feels like I was run over by a cement roller right after I wake up. I get plenty of sleep, but I wake up feeling sore and even more tired than I was when I went to sleep."
>
> "To me chronic fatigue feels like when you're in the water at the beach and you try walking out of the water against the waves as they pull back into the ocean and you feel as if you're not actually moving, you're just walking in the one spot, and it's heavy and your legs ache but you're not getting anywhere. All. The. Time."
>
> "Swimming in a fur coat after running a marathon. Exhausted without earning it. Most people know what it feels like to work yourself to exhaustion, but can't imagine feeling like that and not accomplishing anything more than moving from your bed to the sofa for a change of scenery."

These metaphorical descriptions of CFS are representative of the ubiquity of metaphor in people's experiences of their bodies. The question is whether the various linguistic metaphors seen above (e.g., "I was run over by a cement mixer" and [it is like] "Swimming in a fur coat after running a marathon") are just examples of talk and/or may be critical indications of people's metaphorical conceptualizations of their CFS bodily experiences. Metaphor is often highlighted as a rhetorical tool that is necessary because it allows people to express themselves concerning topics which are otherwise impossible to describe using literal language (Ortony, 1975). My basic claim, however, is that metaphorical talks about the body and bodily experiences are a reflection of how people think about their bodily selves (i.e., the

"metaphorical embodiment hypothesis"). This possibility has important implications for theories of metaphorical thought and language, as well as for how cognitive scientists, and others, characterize the human body and our experiences of embodiment.

This chapter provides an initial discussion of the "metaphorical embodiment hypothesis." I begin by briefly surveying some highlights of the extensive literature on the ubiquity of metaphorical cognition, especially in relation to abstract thought. Following this, I present several representative examples of the myriad of ways that people talk about their basic bodily experiences via metaphor, including their disordered, ill, bodies. The next section considers some possible skeptical responses to the "metaphorical embodiment hypothesis," and I conclude the chapter with a methodological imperative along with a comment on the importance of these ideas for theories of metaphor and discussions of embodiment in cognitive science.

Embodied Metaphor in Language, Thought, and Action

The major revolution in metaphor studies over the last 40 years is the demonstration that metaphor is a fundamental part of human cognition, and not just a poetic, rhetorical device (Gibbs, 1994, 2017; Kövecses, 2010; Lakoff & Johnson, 1980, 1999). Metaphorical concepts, known as conceptual metaphors, enable people to think concretely about abstract entities and experiences. These conceptual metaphors partly motivate the specific ways people speak metaphorically about their lives and the world around them. The original empirical evidence for conceptual metaphors comes from the systematic analysis of conventional expressions in different languages. For example, consider the following short list of conventional expressions:

Greta is making good progress toward her Ph.D. degree.

John has already reached several career goals.

David ran into a rough patch trying to solve the difficult math problem.

Sandra was completely stuck figuring out what to do after her divorce.

Lakoff and Johnson (1980, 1999) argued that these expressions are conventional manifestations of an underlying metaphor in thought, namely, the ŏŰnň ŰŖ ń ŏŒŘŕőňŜ conceptual metaphor. Each linguistic expression above refers to a different correspondence that arises from the mapping of our familiar, often embodied, understanding of journeys onto the more abstract idea of life (e.g., difficulties in life are conceived of as obstacles on the physical journey). The phrase LIFE IS A JOURNEY is only a schematic label for a rich, complex set of knowledge in human minds of the many mappings between journeys and different facets of living one's life.

There is now an extensive literature from cognitive linguistics showing that conceptual metaphors have a critical role in the creation and meaning of many conventional metaphorical expressions, novel metaphors, polysemy, certain text inferences, gesture, and other multimodal metaphorical expressive actions (Gibbs, 2017; Lakoff & Johnson, 1999). A vast body of experimental research within psycholinguistics and cognitive neuroscience also demonstrates that people actively recruit conceptual metaphorical knowledge during immediate and more reflective aspects of metaphorical thinking and verbal metaphor use (Gibbs, 1994, 2017). Much of this research is consistent with proposals that conceptual metaphors are often grounded in recurring patterns of bodily experience (Gibbs, 2006, 2017; Lakoff & Johnson, 1999).

For example, our understanding of journeys emerges from the varied SOURCE-PATH-GOAL sequences we physically engage in repeatedly in everyday life. The mapping of journeys onto concepts related to life gives rise to a highly embodied conception of the more abstract idea of life.[3] People likely have many hundreds of conceptual metaphors, and any single type of conceptual knowledge, such as about life, may be structured through several different conceptual metaphors (e.g., LIFE IS A JOURNEY, A LIFETIME IS A DAY, LIFE IS A CONTAINER, LIFE IS A GAMBLE, LIFE IS A PLANT, etc.). Conceptual metaphors not only motivate the creation and meaning of linguistic metaphors, but also metaphorical gestures, music, art, film, dance, and many other forms of expressive human action (Cienki & Müller, 2007; Forceville & Urios-Aprial, 2009; Gibbs, 2017). Metaphor is truly conceptual and not just a special linguistic device.

A critical part of metaphorical thinking arises from embodied simulation processes (Gibbs, 2006, 2017). These processes involve people imaginatively projecting themselves into different real-world and fictional scenarios, such as thinking of one's constant fatigue in terms of being run over by a cement truck each morning. Embodied simulation processes arise throughout our day-to-day interactions with the physical and cultural world. When you look at a coffee cup sitting on a table and decide to pick it up and drink from it, the movements you make are guided by tacit embodied simulation processes in which you imagine the different actions you can do upon the cup. This enables you to specify exactly what movements you must engage in to successfully pick up and drink from the cup. When reading one person's account of suffering from Chronic Fatigue Syndrome, who says that she feels as if she was run over by a cement truck each morning, we understand her meaning by creating an embodied simulation of what it must be like for one to be run over by a cement truck each morning. These simulations are embodied, and not just similar to abstract computer simulations (e.g., plotting the course of a weather system over a land mass), precisely because they emerge from the dynamic interactions between real brains, bodies, and the world.

There is a great deal of behavioral and cognitive neuroscience research that supports these claims about the ubiquity of embodied simulations in many aspects of human meaning making (Bergen, 2012). Studies have shown, with both humans and non-human primates, that motor areas of the brain are activated when individuals see other actors performing different bodily motions (Grafton, 2011). These findings imply that people tacitly imagine themselves performing the actions they perceive, which enables them to understand through simulations what other individuals are doing.

Psycholinguistic studies have also shown that readers actively imagine themselves moving their bodies in particular ways when they see statements such as "John pulled open the drawer" (i.e., the movement of bringing something closer to the body) and "John closed the drawer" (i.e., the movement of pushing something away from the body) (Glenberg & Kaschak, 2002). Even conventional metaphorical phrases, such as "grasp the concept," are interpreted by imagining grasping onto some objects, or the metaphorical object of a concept,

which can then be inspected and understood (i.e., why it makes sense to use “grasp the concept” and mean “understand the concept”) (Wilson & Gibbs, 2007). Interpreting “Our relationship is moving along in a good direction” appears to involve people imagining themselves moving along some path to some desirable location, or goal (Gibbs, 2013). We do not understand language abstractly (e.g., by recovering underlying meaning propositions), but by embodying the actions, even when those actions refer to events that are impossible to perform in the real world (e.g., grasp the concept).

This collective research on embodied conceptual metaphors clearly shows that many aspects of abstract thinking are linked to past and ongoing bodily experiences. Many scholars have argued that this research helps close the gap in the traditional divide between minds and bodies, and is a critical source of evidence in favor of “embodied cognitive science” (Gibbs, 2006; Lakoff & Johnson, 1999).

It is curious, though, that the studies on embodied conceptual metaphors still implicitly embrace a dualism between minds and bodies. Even if minds are partly metaphorical and grounded in embodiment, the body itself is seen as purely physiological which is not ordinarily understood in symbolic, metaphorical ways. My claim is that our bodies, and our experiences of embodiment, are fundamentally interpreted via metaphor, similarly to the ways abstract thinking and cognition are substantially structured through metaphor.

Metaphor in Basic Bodily Actions

A first clue to the ways that metaphor is critical to bodily experience is seen in an examination of different idioms and proverbs. Most descriptions of bodily actions may seem to reflect non-metaphorical thinking and are presumed to only convey literal, physical meanings. But a closer look at certain linguistic expressions regarding bodily actions reveals that these statements also immediately convey metaphorical messages. Consider the following English idiomatic expressions:

go out on a limb
skating on thin ice

rock the boat
spill the beans
get away with murder

When these phrases are used in literal, physical contexts to describe different human actions, they automatically evoke their figurative, metaphorical meanings. When one "goes out on a limb," one is metaphorically also in a precarious, potentially dangerous situation. The same idea applies to literal uses of "skating on thin ice" and "rock the boat." When one literally "spills the beans," he/she is also metaphorically expressing the idea that some materials are now suddenly revealed for all to see. And when one literally commits murder, and gets away with this crime, one metaphorically has engaged in a terrible action and has not had to suffer any penalty for doing so.

Many proverbial expressions also convey metaphorical ideas when employed in purely literal circumstances. For example, the suggestion "don't count your chickens before they are hatched," in the context of chicken hatching immediately conveys the broader symbolic message of not prematurely doing something before some precondition has been met. Similarly, "the early bird captures the worm" when used literally in talking about early morning bird behavior immediately evokes the message that getting a head-start in one's daily activities is likely to lead to greater success than if one delays. Experimental studies show that people quickly infer metaphorical meanings when they hear idioms and proverbs being used literally (Gibbs, 1980, 1986).

People's ability to routinely interpret linguistic descriptions of physical actions in metaphorical ways is one reason why they are able to create and make sense of allegorical literary texts. Writers and poets often express broader metaphorical, allegorical, ideas through their depiction of mundane bodily actions and experiences in different real-world contexts. A good example of this is seen in a well-known work by Frost (1969) titled "The Road Not Taken." The poem begins, and later ends, in the following way:

Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveller, long I stood

And looked down one as far as I could
To where it bent in the undergrowth;
.....
I shall be telling this with a sigh
Somewhere ages and ages hence;
Two roads diverged in a wood, and I-
I took the one less traveled by,
And that has made all the difference.

Most people recognize that this poem is not, just superficially, about a person walking through the woods, but expresses symbolic meaning about living one's life. One study asked college students to write out their interpretations of different parts of the poem, and over 85% gave evidence of understanding the poem's metaphorical, perhaps allegorical, meanings (Gibbs & Boers, 2005). One does not have to be a literary expert to infer symbolic meanings regarding bodily actions given our bred-in-the-bone impulse to think and act in metaphorical ways (Gibbs, 2011), particularly given common understandings of the conceptual metaphor LIFE IS A JOURNEY. Simply seeing a linguistic description of a simple human action, such as walking through the woods, almost immediately evokes metaphorical ideas.

Many other basic human actions may also be experienced and understood in metaphorical ways. Our sensory experiences of smell may be metaphorically complex (Kövecses, 2019). Consider the expression "The air was filled with a pervasive smell of chemicals." This statement implies that smell is a substance that is contained in a specific object or location. This example suggests the presence of different underlying conceptual metaphors, including SMELL IS A SUBSTANCE, THE LOCATION OF A SMELL IS A CONTAINER, and THE EXISTENCE OF SMELL IS FOR THE SUBSTANCE TO BE IN THE CONTAINER. The statement "The skunk gives off an unpleasant smell when attacked" suggests that a particular smell comes into existence as a transition from being one object (e.g., the skunk) to becoming a larger container in a specific location. This expression is motivated by the conceptual metaphors SMELL IS AN OBJECT, CAUSING SMELL IS TRANSFERRING THE OBJECT, and THE SOURCE OF SMELL IS A SURFACE.

The intensity of smell is also metaphorically understood. Consider the statement "There is an overpowering smell of burning tires," which suggests that INTENSITY OF SMELL IS STRENGTH OF EFFECT. The phrase "The cheese smell was quite sharp" emerges from the conceptual metaphor INTENSITY OF SMELL IS SHARPNESS OF AN OBJECT. Finally, the sense of smell as something we can not entirely control is seen in "Then the pungent smell hit us – rotting fish and seaweed." This expression is motivated by SMELL IS A PHYSICAL FORCE, INTENSE SMELL IS A STRONG PHYSICAL FORCE, and SENSING AN INTENSE SMELL IS COMING INTO CONTACT WITH A STRONG PHYSICAL FORCE.

These are just a few of the ways that metaphorical concepts help structure our experiences of smell (Kövecses, 2019). Eating seems to be another purely physical activity with an entirely biological function of keeping our bodies alive and healthy. We cultivate and prepare certain foods to be desirable in order to motivate the functional behaviors of eating for living. Yet eating is also often conceptualized in metaphorical ways. Consider a passage from "The Ultimate Fast Metabolism Cookbook" (Rockridge, 2007), which suggests that food is "software" that you can:

> "load into your body and get it to perform different functions by providing it with different types of information… Depending on what you eat, different types of your DNA hardware are expressed or turned on…Whole foods turn on the health and weight-loss genes. Processed foods, high in sugar and trans-fats, turn on the disease and weight-gain genes. The most powerful tool that you have to change how your genes function is your fork (2007: 8)."

This metaphorical vision of eating food as loading software into your hardware system, even if somewhat simplistic, offers a conception of eating that will hopefully lead people to adopt better eating behaviors. Metaphorical conceptions of what is best to eat are not abstractions, as they become deeply embodied beliefs that guide people's eating behaviors. For example, one study asked Canadian adults about their eating behaviors, especially those related to "healthy

eating" and maintaining a "healthy body" (Spoel et al., 2012). Three metaphorical themes were discerned as critical aspects of the ways the adults described healthy eating: HEALTHY EATING IS BALANCED EATING (e.g., "I try to eat a balanced diet as much as I can"), FOOD AS FUEL (e.g., "Most of the time we aim to put good fuel into our bodies"), and FOOD AS JUNK (e.g., food as "junk," "garbage," "waste," "rubbish," "poison," or "pollutants").

These three metaphors do not exhaust some of the complex symbolic ways that people think of their ordinary eating activities. Consuming certain foods and drinks can take on even higher-order metaphorical values. Participating in a Passover Seders is loaded with metaphorical meaning, as certain foods are linked with different symbolic ideas. Eating horseradish on gefilte fish tastes bitter and is metaphorically linked to the emotional bitterness of enslavement that Jews experienced in Egypt. Holy Communion in many Christian religions is structured around the eating of bread wafers and drinking of wine as symbolically standing for the body and blood of Christ. These metonymic relationships tap into larger metaphorical themes in which we understand EATING THE BREAD AND DRINKING THE WINE IS MAKING CONTACT WITH THE SPIRITUAL ESSENCE OF CHRIST. More dramatically, several tribal communities around the world still practice cannibalism, not because of a need for food, but because of the metaphorical relationship between eating one's relative and showing respect for that individual (Nicholson, 1991).

Pain is another bodily experience that is typically understood and expressed through metaphor. Cognitive linguistic studies reveal that there are a variety of conventional metaphors seen in people's talk of pain. Consider some of the ways that people describe their pain, along with the conceptual metaphors that motivate these specific statements (Semino, 2010):

> "A sharp stab of pain made her sit back down."
> (PAIN IS A SHARP OBJECT)
> "A massive killing pain came over my right eye [...] I clawed at my head trying to uproot the fiendish talons from their iron grip."
> (PAIN IS A TORMENTING ANIMAL)

"Pain is fire that can devour the whole body."
(PAIN IS FIRE)

We also frequently experience pain in terms of our interaction with different objects, as seen in the following examples and the specific words used to describe pain:

INSERTION OF POINTED OBJECTS
"stinging," "pricking," "boring," "drilling," "penetrating"
APPLICATION OF SHARP OBJECTS
"sharp," "cutting," "lacerating," "stabbing," "piercing"
PULLING/TEARING
"tugging," "pulling," "wrenching," "squeezing," "tearing"
APPLICATION OF PRESSURE/WEIGHT
"pinching," "pressing," "crushing," "tight," "heavy"

Metaphorical descriptions of pain allow listeners (e.g., physicians and therapists) to create detailed embodied simulations of what it must be like to be the person experiencing pain, which enhances interpersonal empathy for what the sufferer has been going through. The "McGill Pain Questionnaire" (Melzack, 1975) implicitly invites participants to think of their pain in metaphorical ways given questions such as "What does your pain feel like?" and "How strong is your pain?" (where "strong" is essentially understood as a metaphorical idea). In other parts of the questionnaire, participants are asked to rate whether their pain could be characterized in many different ways, such as "flickering," "jumping," "flashing," "shooting," "drilling," "stabbing," "sharp," "cutting," "lacerating," "pressing," "gnawing," and "wrenching," with several of these terms possibly reflecting metaphorical ideas about pain experience.

Talk about pain is partly motivated by people's recurring bodily experiences of interacting with objects in multiple sensory ways that are then recruited to think of their various pain sensations in meaningful ways. We understand pain talk through embodied simulation processes in which we imagine ourselves experiencing the different bodily actions mentioned in the discourse (e.g., we know what it is like to pull something apart, which gets mapped to understanding

specific inner, painful sensations). These bodily based metaphors also allow speakers to coordinate with others, such as physicians, to describe their pain experiences in publicly shared, and seemingly objective, ways, a process that may often, but not always, facilitate treatments to alleviate the pain (Lascaratou, 2007).

Another place where metaphor arises within disturbances of the body is when women face difficulties with nursing infants. Breast-feeding a child may, to some, seem instinctive, but like many facets of life can be really difficult in both physical and emotional ways. Consider how one woman wrote of the very different personal metaphors that arose during different stages of nursing her daughter.[4] She most generally acknowledged that "There was no metaphor that captures the many phases I went through as a first time nursing mom." For her:

> "The first three days – were like puberty. I was massively sweaty and my shirts were way too tight. My breasts felt suddenly powerful yet completely overwhelming. I cried all the time."
>
> "Days 4–6 – were like assembling a bookshelf from IKEA. I knew if I could just get the DANG positioning right it would all come together. I looked at diagram after diagram and it appeared so easy in the pictures. But each new attempt left me bruised, demoralized, and frustrated."
>
> "Days 7–18 – were like S&M. The pain was so bad I wanted to puke but I went back for more every two hours. Many people told me that my experiences did not sound normal; they speculated that perhaps there was something very wrong with what I was doing. They suggested I seek professional help."
>
> "Days 19–50 – were like learning the guitar chords to your very favorite song. It was hard, there were blisters, but they weren't too bad; certainly nothing that would stop me. Each day it got easier. Eventually the blisters were gone, my hands moved with ease, I just knew what to do. I could finally experience it, like a song. I felt so proud, I felt like telling everyone, 'Do you see this! Check me out. I'm going to do this everywhere. I'm going to do this right in your face! I'm a total rock star!"
>
> Later on, "Two years to two years, four months – were like the last two hundred pages of a very good book. I slowed down, I

> paid very close attention, I did not want it to end. I was not sure what would happen after I finished. I sensed that I would feel a little bit empty."

These descriptions of one woman's bodily experiences of nursing again illustrate that we can embrace multiple, sometimes contrasting, even contradictory, metaphors to conceive of our adaptive challenges in life. Once more, readers can come to understand what the woman was bodily experiencing through detailed embodied simulation processes elicited by the metaphorical language she employed.

Anorexia nervosa is another complex illness in which individuals create metaphorical understandings of their bodily symptoms. Rather than expressing their experiences using metaphorical language, patients often refer to bodily states as being metaphorically connected to larger psychological, emotional, and spiritual ideas or concerns. Talk of anorexia nervosa using "concrete metaphors" draws an immediate connection between bodily and emotional experiences (Enckell, 2002). Examples of this are seen in one study of ten female patients, aged 16–35, who described their experiences of anorexia nervosa (Skarderud, 2007). They referred to several larger psychological themes in their interviews.

For example, one woman talked about her emotional emptiness and her disease in the following way:

> "Some days ago I should have had a meeting with my boss. I was anxious about this. Then I decided to vomit. I couldn't stand having the lunch in my stomach. I cannot have anything in my stomach, because then I cannot concentrate. I need to be empty to feel alert."

The woman did not use much metaphorical language, but still alluded to metaphorical connections between the physical act of keeping her stomach empty with the psychological process of keeping her mind clear and alert.

Purity is a different theme seen in the woman's talk of anorexia, which, in this case, draws associations between bodily purity with asceticism and spirituality. Anorexic patients spoke openly about their

devotion to purity in their lives, showing a strong metaphorical link between attempts for purity in their eating and bodily make-up with their struggles for emotional stability in their lives. One woman reported that her illness was focused on becoming pure. “I became so pure, I hadn’t sullied myself with food, conversation with others, or dirt on my body.”

Some patients talked a good deal about removing or eliminating their body weight as a way of dispensing with their negative self on the path to constructing a new self for a “new start.” One woman demonstrated this understanding when stating:

> “When I was in hospital, admitted because of my extremely low weight, I remembered thinking that this is good. The old, chaotic, unhappy me is gone, and this is a new opportunity. Now I am down to bedrock. And this time I will be another person.”

This extract shows how one’s psychological identity can be metaphorically related to the concrete body, which is typical of individuals with anorexia nervosa. The drive for thinness is not simply about reducing weight, but much more symbolically understood as using self-starvation to attain a purer, better self.

Many serious body disorders are almost always described in rich metaphorical terms. Cancer is one disease that is understood in diverse metaphorical ways. In one study, six women, who were recovering from different forms of cancer, were individually interviewed about their illnesses, particularly focusing on how they tried to come to terms with the idea of having cancer, feeling ill, having treatments, and attempting to heal (Gibbs & Franks, 2002). A cognitive linguistic analysis of these narratives revealed 796 individual linguistic metaphors that reflected 22 different metaphorical concepts. Each person produced on average 132 metaphorical expressions in the 20–30 min interviews (i.e., more than four metaphorical phrases per minute). Much of what the women talked about reflected highly conventionalized ways of metaphorically understanding different aspects of illness and healing experience. Yet, these conventional metaphors were not simple clichéd, dead metaphors, but instantiated

enduring, conceptually alive ways of metaphorically structuring the women's understandings of what was happening to them.

For example, the metaphorical mapping of CANCER IS AN OBSTACLE ON LIFE'S JOURNEY served as the conceptual foundation for over 38% of all the women's verbal metaphors (and was found frequently in each of the six women's narratives). These narratives illustrated in different ways how cancer is pervasively seen as a part of the trip or an obstacle in the journey of life. Cancer is something one "starts" and "finishes" just like a journey. One woman who was recovering from breast cancer said, "I'd say for about the last year I've felt quite finished with it (cancer), like it's done. It's over." Participants very frequently talked about cancer and treatments as something to "get through," "move into," and "get over." In this sense, cancer is often seen as something you can travel into and out of, as if cancer were a particular location in the real world.

When one's life journey is challenged by illness, alternative paths sometimes open up to help individuals move forward for the better. Consider one example of this in the context of a woman, in her late 40 s, describing being diagnosed, treated, and then slowly recovering from cancer (Gibbs & Franks, 2002). She mentioned beforehand that some of the imagery in her tale emerged from an earlier dream sequence.

> "Dance with me," cancer commanded. "No," I shrieked in a fusion of fear and disbelief. I wanted nothing to do with this would-be suitor, and I surely couldn't comprehend why he had chosen me in the first place. Before I could make sense of the insanity, I realized that this dance was not optional. Cancer's clutch was firm as he led me to the floor. Arm and arm we were clumsily stepping to the awkward beat of chaos. The dance he had choreographed for me was riddled with mismatched moves.... Like a lifeless rag doll, lifelessly pinned to my partner's twisted movement, I was spun in circles of sadness until I was left physically and emotionally exhausted. Just when I was sure I could dance no more, another dramatic change in tempo took me by surprise. My partner and I came face to face. Our eyes locked in fury. We seemed much less like dance partners now; but more a matador and the bull ready for the fight. ... The new

> beat brought on the realization that no longer need I follow in this dance. … My spirited moves were carefully planned, precise, and perfectly timed with a new unfolding song. … The distance between cancer and me increased. … As the song faded into the past, I found myself dancing solo. I stopped, caught my breath, and smiled. Then I slowly exited the dance floor a wiser and more beautiful person.

This woman was creative in her poetic expression, particularly in the way she spun an extended metaphor to describe different facets of her illness and her new path toward recovery. But her narrative was still rooted in several conventional patterns of metaphorical thinking, especially in terms of understanding her illness as a particular type of journey, namely, a dance performance. This metaphorical conception led to the recruitment of several conventional conceptual metaphors, such as FIGHTING ILLNESS IS A PHYSICAL BATTLE WITH A HUMAN OPPONENT, ILLNESS and SUFFERING IS A PHYSICAL JOURNEY (related to the widespread metaphor LIFE IS A JOURNEY), which is a more specific depiction of the conceptual metaphor INTERACTING WITH OTHERS (including illness as other people) IS A DANCE metaphor. Other common metaphors that motivated the woman's narrative include EMOTIONAL CONTROL OVER A PERSON IS HAVING TIGHT PHYSICAL CONTROL OVER THAT PERSON'S MOVEMENTS, CHAOTIC EMOTIONAL AND PHYSICAL EXPERIENCE IS DISCORDANT MUSIC, CLARITY IN THINKING IS CLARITY IN SEEING, and LESS PHYSICAL CONTACT WITH ANOTHER PERSON IS LESS EMOTIONAL / PSYCHOLOGICAL CONNECTION WITH THAT PERSON.

Some bodily experiences may be metaphorically understood in more positive ways. For example, sexual physical sensations and actions are typically described via multiple action metaphors (Kövecses, 2010). Some common metaphorical concepts for sexual behavior include the following:

SEX IS PLAYING SPORTS
SEX IS WAR
SEX IS HUNTING
SEX IS EATING

SEX IS FIRE

Sexual intercourse is also understood through various other metaphors. One example of this is seen in a study of 14–19-year-old teenagers from Malawi who were asked to describe their behaviors and attitudes about sex, especially in relation to attempts to reduce unwanted pregnancies and HIV/AIDS (Undie et al., 2007). An analysis of these in-depth interviews revealed three major metaphorical themes through which these young adults conceptualized sex. SEX IS A UTILITARIAN ACTIVITY focuses on the mechanisms of sexual activity and the utility of different sexual actions. This metaphorical understanding of sex for Malawi youth is evident when they speak of sex in terms of "brushing one's teeth" or even as "putting Colgate on a toothbrush" where the toothpaste refers to the male's penis and the toothbrush to female genitalia. The SEX IS A UTILITARIAN ACTIVITY metaphor downplays the interpersonal and social aspects of sexual intercourse, given its primary focus on how sex and sexual practices are commonplace and changeable.

The second conceptual metaphor by which Malawi youth understand sex is SEX IS A PLEASURABLE ACTIVITY. For example, these teenagers sometimes describe their dislike of wearing condoms because "you can't eat candy while it's in the wrapper. It doesn't taste good." Also, "it is better to have sex meat to meat because if a person wants to eat a banana, do they eat it along with the peels?".

Finally, the metaphor SEX IS A PASSIONATE ACTIVITY arose when participants talked about "breaking" one another, or "finishing" each other, each of which implies that sex is a vigorous, rewarding bodily experience that ends with each person fully "spent." Both males and females talked of having sex for the first time as "removing dust," which comes at the end of sex first "raising dust" before the dust is finally removed from the bodies/genitalia of the participants.

This single study is representative of much cognitive linguistic research on the prominence of metaphor in people's talk about sex (cf. Weatherall & Walton, 2010). These metaphorical phrases often unfold in discourse to reveal larger symbolic meanings of thinking about sexual activity. Asking people to critically reflect on their own metaphors may be particularly helpful in alerting young adults about

risky sexual behaviors, as well as overcoming certain negative impressions about sex.

Even physiological sexual responses are characterized in metaphorical terms. One study asked speakers from 27 languages to "describe terms for orgasm as well as the announcements they use before having an orgasm in their native language" (Chiang & Chiang, 2016). Many languages focus on orgasm in terms of the following general metaphorical idea:

ORGASM IS A DESTINATION		
Source: JOURNEY		Target: SEX
Travelers		participants
distance covered		progress made
decisions about way to go		choices over what to do
destination of the journey		orgasm

A more specific instantiation of the destination in orgasm is seen in the following metaphor, with some examples from different languages:

ORGASM IS THE PEAK OF A TIDE
"highest peak" (English and Indonesian)
"sexual peak" (Korean)
"point highest" (Thai)
"high tide" (Mandarin Chinese)

Each of the above metaphors are also motivated by the idea of HAPPY IS UP. Still, there is some variation between languages in the exact nature of travel to and from the destination of the orgasm. Consider two different ways of announcing orgasm:

"I'm coming" (toward orgasm place or hearer)
"I'm going" (away from orgasm or hearer)

The "going" idea also refers, in some languages, to moving toward heaven as in Japanese and French (i.e., "la petite morte").

This linguistic evidence strongly suggests that sexual orgasm is understood in diverse metaphorical ways which are always informed

by enduring cultural beliefs and values.

Some Remaining Methodological and Theoretical Questions

The abundant linguistic evidence showing pervasive patterns of metaphorical thinking in people's talk of their bodily experience clearly requires close study and explanation. People do not use metaphorical language in arbitrary, haphazard ways, as their metaphorical talk is motivated by complex cognitive, cultural, and experiential forces. Nonetheless, some scholars, especially within the cognitive sciences, may be skeptical about the metaphorical embodiment hypothesis. Let us imagine some possible responses to my arguments in this chapter about the metaphorical body.

First, one can argue that the metaphorical manner in which basic bodily experiences are discussed is purely a social, communicative phenomenon and not truly a conceptual one. Bodily experience may be best characterized as "pristine," "non-symbolic," and purely "biological." Linguistic metaphors for bodily sensations may only be euphemisms that are created to avoid speaking directly of delicate, sometimes embarrassing, bodily functions. The fact that people speak metaphorically of their bodies and bodily experiences should not, under this perspective, be taken as direct evidence for the metaphorical embodiment hypothesis.

This skeptical response assumes, incorrectly, that non-metaphorical, or literal, language is most capable of fully describing bodily sensations and functions in an objective, scientific manner. The language of science presumably captures this more literal, non-metaphorical understanding of the body. But scientific descriptions of the human body, across time and cultures, are notoriously metaphorical in nature. Metaphor is not ornamental to bodily experience, but defines it in irreducible ways. We need not scrape metaphors away to reveal the true, inner contents of human bodily experience for the metaphors themselves are basic tools by which we create meaning for ourselves and others. This observation is unsurprising given that scientific theories of the natural world are fundamentally based on metaphorical conceptualizations (Brown,

2003). It is unclear, then, that it is ever possible to reduce metaphorical talk about the body to some objective, non-metaphorical scientific theory. Science itself is a metaphorical enterprise.

A different skeptical reaction to my claim is that there is a fundamental difference between bodily sensations and the conceptualizations of these experiences. Our bodily feelings arise prior to any particular conceptualizations of these sensations. Basic sensations (e.g., taking journeys, smells, tastes, feeling pain) may come first, and we ascribe metaphorical interpretation to these only at a later stage of processing.

There are several responses that one can offer in this skeptical reaction. First, at a general level, the classic divide between sensation, perception, and conception is now widely questioned in psychology and other disciplines, given different lines of evidence that argue against "pure" sensation apart from an individual's cognitive appraisals of those sensations (Schiffman, 2011). Within neuroscience, there is also more and more research demonstrating the existence of diverse, interactive connections between different sensory brain areas and between sensory neural systems with areas associated with higher-order cognition (Shapiro & D'Espisito, 2016). It is by no means evident that metaphorical talk of the body only reflects a level of phenomenological experience, which is above, and separate from, how people actually experience their bodies in diverse ways.

Beyond this changing perspective on the complex neural interactions between sensory and cognitive functioning in the human brain, more specific studies in cognitive neuroscience reveal tight associations between metaphorical thinking and language use with sensorimotor brain activity. Sensorimotor brain activation has been observed during the comprehension of metaphorical language, such as metaphors and idioms. For example, reading an abstract transfer statement (e.g., "give the news") activates the motor system exactly as does seeing concrete transfer expressions (e.g., "give the pizza") (Glenberg et al., 2008). When people read metaphorical action phrases, such as "grasp the concept," there was nearly identical activation in motor areas of the brain as when participants saw literal action statements (e.g., "John grasped the straw") (Desai et al., 2011). Listening to taste metaphors (e.g., "She looked at him sweetly") or

auditory metaphors (e.g., “Her limousine was a privileged snort”) also showed an increased activation in relevant somatosensory brain areas (Citron & Goldberg, 2014). People appear to interpret metaphorical language as if they were bodily engaging in the very actions alluded to in metaphorical discourse.

Many metaphor scholars assume that metaphorical mappings are uni-directional, in which bodily source domains are projected onto more abstract target domains (e.g., the mapping of physical journeys onto life). If this idea is generally true, metaphorical meanings arise primarily in the context of abstract thinking. Our understanding of bodily source domains should be mostly untouched by metaphorical concepts. Still, some metaphorical expressions are more bi-directional in terms of the complex meanings that are conveyed (e.g., AFFECTION IS WARMTH and WARMTH IS AFFECTION).

In addition, the constant body to mind metaphorical mappings surely exhibit feedback from the newly structured target domain back to the source, as when people come to understand their bodily experiences in more symbolic, metaphorical terms related to their conceptualizations of life. Metaphorical mappings may give rise to complex resonances between bodily experiences and abstract concepts, as well as between different kinds of bodily experiences from different modalities (e.g., as seen in many synesthetic metaphors such as “loud tie”). There is no reason to assume, then, that basic bodily sensations and experiences are separate from metaphorical meanings.

One can still seek more direct evidence to support the metaphorical embodiment hypothesis. How do we know that metaphorical concepts, and their linguistic realization, have some direct connection to bodily experiences? Different experimental findings demonstrate entrenched connections between metaphor and bodily sensations and actions. Many bodily experiences can automatically activate metaphoric association regarding bodily actions and different social concepts and judgments (Landau et al., 2014). For example, when people hold a warm cup of coffee, this facilitates their judging strangers as being more affectionate, generous, and trustworthy (Williams & Bargh, 2008). After recalling an unethical act they had previously performed, people prefer to accept a gift of antiseptic hand-wipe than a set of pencils for their participation in the experiment (Zhong & Liljenquist,

2006). Within the olfactory domain, one study with English speakers examined whether smelling something ishy would raise people's suspicions about others when playing a trust game (e.g., "There was something ishy about John's new business scheme") (Lee & Schwarz, 2012). People were led to a room that had been sprayed with ish oil, a fart scent, or odorless water. When these participants smelled something ishy, as opposed to the other smells, they were less willing to contribute money toward a publicly shared resource, indicating greater social suspicion in the ishy smelling condition. Finally, participants who sat in a clean-scented room exhibited greater reciprocity in a trust game, and donated more money to a non-pro it organization than did people who sat in a neutral-smelling room (Liljenquist et al., 2010). These results are consistent with the idea that the conceptual metaphor SUSPICION IS A FISHY SMELL in uenced people's social judgments.

Most generally, physically experiencing an embodied source domain (e.g., feeling warm, smelling something ishy) can automatically prime people to think about a speci ic target domain (e.g., affection, suspicion) and draw a metaphorical relationship between them. These metaphorical associations are rarely recognized consciously in people's ongoing daily experience. Participants in these studies were still performing metaphors as shown by their various social judgment behaviors. They were not, however, enacting metaphor in the sense of irst having a full-blown metaphorical concept in mind before they engaged in speci ic metaphorical performances (e.g., judging whether a person was affectionate or trustworthy).

Of course, there are many boundary conditions that modulate exactly when embodied actions give rise to metaphorical effects in these psychological studies. Several possible theoretical mechanisms have been proposed regarding why these metaphorical embodiment effects automatically arise in everyday life, such as phylogenetic factors (e.g., evolved bodily associations between warmth and affection), ontogenetic (e.g., early childhood experiences of the physical world leading to correlations between psychological distance with spatial and temporal distance), and linguistic in uences (e.g., culture-speci ic metaphors such as "bright smile") (Bargh et al., 2012). All three of these, along with other possible mechanisms, may combine

to explain the various metaphoric associations which automatically arise in bodily experience.

A different source of evidence in reply to skepticism over the connection between metaphor and bodily experience comes from studies that explore whether making patients aware of their metaphorical thoughts about their illnesses may modify their felt bodily experiences of being ill. There are many dozens of clinical and experimental studies showing that altering caregivers' (i.e., doctors', nurses', therapists') metaphors can signi cantly enhance their communication with patients, not only in terms of helping patients to better understand their injuries or illnesses, but also in terms of helping individuals feel more connected to caregivers (Sims, 2003). Framing health messages using particular metaphors often increases people's adherence to speci c kinds of health-promoting behaviors (e.g., following certain diets, taking medications, going in for regular screenings to detect speci c diseases) (Landau et al., 2018; Pinheiro et al., 2017; Spina et al., 2018).

The critical question, however, is whether paying attention to the speci c metaphors employed in understanding one's illness, and possibly adopting alternative metaphorical ways of thinking about one's experience of illness, can actually change how people physically feel. Obtaining this kind of evidence is dif cult because people are normally asked to describe their bodily symptoms (e.g., pain) using words. What individuals say about what they feel is surely an important measure in assessing how they feel.

Still, it is not always clear that how we talk about our bodily experiences is necessarily an unbiased account of how we physically feel. Psychotherapists, for example, have often wondered if clients' narratives, which often contain rich metaphors, sometimes offer a distorted re ection of what clients are emotionally experiencing, particularly when recounting psychologically meaningful events (cf., Siegelman, 1993 for discussion of this issue). Certain physicians also voice concern over having anorexia nervosa patients read memoirs about individuals struggling with anorexia because the language employed may seduce a person into adopting overly romanticized views of their illness (Skarderud, 2007). There will always be

reasonable skepticism about what metaphorical talk says about what people are really experiencing with their bodies.

Nonetheless, changing one's metaphorical understanding of a bodily injury or illness seems to have a positive effect both in terms of what people are physically feeling, as well as how they are psychologically adapting to their illness. Quite a few studies have investigated the influence of metaphorical priming on different perceptual judgments. For example, simply being exposed to certain metaphors can alter people's perceptual judgments. Showing people a picture of a heavy object in the lower part of the frame facilitates people's subsequent judgments that a coffee drink tastes strong given the implicit metaphorical relationship STRONG IS HEAVY (Fenko et al., 2018). People judged pictures to be brighter when they first read positive, as opposed to negative, evaluations, an implicit enactment of the POSITIVE IS BRIGHT metaphor (Meier et al., 2007). Similarly, when people listened to a brief musical segment with positive valence, they subsequently judged certain grey squares to be brighter in color compared to when they first heard musical segments with less positive valence (Bhattacharya & Lindsen, 2016). A different study showed that participants judged smiling faces to be brighter than frowning faces (Song et al., 2012). Finally, when people first listened to background music that was smooth and mellow, they judged wine to taste smooth and mellow, compared to when they heard no music (North, 2012). These different perceptual judgment findings are consistent with the claim that enduring metaphorical ideas can have a direct connection with various bodily sensations (e.g., perceived brightness and taste). Metaphorical meanings emerge throughout mundane bodily experiences apart from when people aim to communicate with one another.

A rather different kind of evidence for the tight connection between metaphorical ideas and bodily experience is seen in clinical studies in which individuals suffer from different maladies and injuries. Metaphor intervention during psychotherapy has been shown to reduce symptomatic expressions of underlying depression, PTSD, and pain and grief (McGuinty et al., 2017; Stott et al., 2010; Witztum et al., 1988). Engaging patients through different exercises to reconceptualize their pain symptoms using various metaphors (e.g.,

LIFE IS A JOURNEY and PAIN IS A NUISANCE rather than PAIN IS AN ADVERSARY) can lead to a signi cant decrease in their reports of pain (Gallagher et al., 2013; Loftus, 2011). Health care providers can also learn to avoid unhelpful metaphors in their talk with patients that may be damaging to individuals' conceptualizations of their bodily disorders (Demjén & Semino, 2016).

These, and many more, studies generally indicate the possible ef cacy in using metaphor intervention to reduce bodily symptoms often associated with psychological and physical disorders. Of course, the success of such metaphor-based programs depends on various factors related to a client's speci c condition, the stage of their illnesses, as well as what metaphors are employed and when they are introduced in the course of therapy. One may claim that the positive effects of metaphorical reconceptualizations of illness and injury re ect more the result of "mind over (body) matter" rather than "mind changing (body) matter." But it is, again, not at all clear if many aspects of bodily experience can really be assessed in objective, non-cognitive, terms. People's understanding of their bodily experiences, via metaphor or any other symbolic mode, are an inherent part of human life.

Another reply to skepticism regarding metaphor's possible role in shaping bodily experience suggests that metaphor arises automatically throughout many forms of everyday bodily performance. One of the most notable, and well-studied, arenas in which metaphor ows directly from bodily action is gesture. People's head and hand/arm movements often re ect underlying conceptual metaphors (Cienki & Müller, 2008). Most gestural metaphors emerge spontaneously in everyday interaction as a matter of integrated thinking for speaking processes. For example, a speaker (talking in German) was describing her rst romantic relationship and said, "Well there I did already realize, well," while repeatedly touching her two open palms together. She then continued, "This is pretty clingy," while her at hand repeatedly touched and moved apart as if the partners were standing together (Müller, 2007: 121). The speaker's gestures enacted the metaphorical source domain before the verbal expression "pretty clingy" was spoken.

Speakers can also express metaphorical ideas using gestures when their co-occurring speech is nonmetaphorical. One examination of students' discussions about honesty when taking exams showed one student stating, "Like dishonest suggests, like, um, not truthful, the truth is what like." When saying "truth," the student made a flat-hand gesture with her left hand in the vertical plane, fingers pointing away from her body (Cienki, 1998). This gesture seems motivated by the conceptual metaphor of TRUTH or HONESTY IS STRAIGHT (e.g., "straight talk") even though nothing in the speech denoted this metaphorical idea.

These automatic bodily performances are usually enacted without much conscious effort or reflection. Metaphorical gestures reveal the close connection between metaphorical thinking and unconscious bodily action. Metaphor shapes not only how people perceive different sensations but also how the whole body conveys metaphorical meanings, which offers another source of evidence in favor of the metaphorical embodiment hypothesis.

Finally, skeptics may argue that experimental evidence, beyond linguistic examples and analyses, is required to best test the psychological validity of the metaphorical embodiment hypothesis. I fully agree with this sentiment. The linguistic data must still be accounted for in some manner, and the motivating presence of embodied metaphorical concepts is clearly relevant to this explanation. Moreover, as discussed earlier, there is a large experimental literature showing that people's metaphorical language in talk of abstract ideas is, to a significant degree, tied to enduring embodied conceptual metaphors. It would be very surprising if similar experimental effects could not also be obtained when people produce and interpret linguistic metaphors about bodily sensations and experiences.

Conclusion

Although metaphor is typically associated with structuring, and talking, of abstract concepts, people also describe their bodies and bodily experiences in complex metaphorical ways. My argument is that the ubiquity of metaphor in people's discourse about their bodies offers

important evidence in support of the metaphorical embodiment hypothesis. Bodily sensations and experiences are often shaped by different metaphorical concepts.

The possibility that bodily experiences are signi cantly metaphorical has many implications for contemporary metaphor theory. Metaphor may not just arise from the mapping of information from non-metaphorical, embodied source domains onto more abstract target domains. Instead, it is critical now to more systematically explore the metaphorical nature of bodily source domains, or bodily experiences more generally. This type of experimental study may reveal that metaphor is even more pervasive in everyday life than has been acknowledged in the past, even by those scholars who are great enthusiasts of the metaphors we live by movement in cognitive linguistics and cognitive science.

At the very least, there is an important methodological imperative that falls out from the "metaphorical embodiment hypothesis," namely, the "metaphorical body imperative": We should always be open to the possibility that bodily experiences themselves are signi cantly constituted by metaphor, and explicitly explore this idea in our linguistic and experiential analyses of metaphor in thought, language, and action. We can no longer simply assume that bodily based experiences are necessarily non-metaphorical.

Time will tell whether the metaphorical embodiment hypothesis is generative of new linguistic and experimental research. But metaphor and embodiment scholars should embrace the metaphorical body imperative as an essential part of their research strategy when exploring links between minds and bodies.

The metaphorical embodiment hypothesis highlights a different possibility for characterizing how metaphor arises in human experience. Rather than suggesting that metaphors are primarily a matter of cross-domain mappings, many metaphorical ideas may emerge via part-whole, or metonymic, meaning construction processes. Particular instances of bodily experiences may be representative of a larger metaphorical category. People's dispositions to draw connections between their here-and-now bodily actions to larger symbolic life themes creates bi-directional correspondences that enable individuals to discern metaphoricity in bodily experience.

Cognitive science now often sees embodied experience as providing the grounding for symbolic, including metaphorical, higher-order concepts that are critical parts of our abstract thinking abilities. But the body itself is experienced in symbolic, metaphoric ways, a possibility that further closes the gap between mind and body. This insight fits in well with theories that view human minds as embodied, enactive, embedded, and extended (Chemero, 2009; Gallagher, 2006; Gibbs, 2006, 2019). Still, the enactive, embedded, and extended nature of human embodiment gives rise to metaphorical ideas through people's ongoing attempts to address various adaptive challenges that are always informed by cultural beliefs and values.

The metaphorical embodiment hypothesis does not imply that every bodily sensation or experience is conceptualized in metaphorical terms. Metaphorical thinking emerges most directly when people encounter difficulties, either in abstract or physical ways, when dealing with adaptive challenges in everyday life. As is the case with metaphor in abstract thinking and language use, metaphor most likely unfolds in probabilistic, partial, ways that depend on a wide range of personal and cultural factors. There is good reason to study metaphor as a major constraint on bodily experience.

Notes

1. https://www.mayoclinic.org/diseases-conditions/chronic-fatigue-syndrome/symptoms-causes/syc-20360490.
2. https://themighty.com/2018/07/chronic-fatigue-what-it-feels-like/.
3. Conceptual metaphorical thinking may be grounded in recurring patterns of bodily experience, but these are always infused with cultural beliefs and values (Gibbs, 2017; Ibarretxe-Antuñano, 2013; Kövecses, 2010). Embodied conceptual metaphors, such as LIFE IS A JOURNEY, are given unique manifestations in different cultural contexts and languages.
4. https://community.whattoexpect.com/forums/may-2010-babies/topic/a-metaphor-for-breastfeeding.html.

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Part II
Cognitive and Neuroscience Perspectives

© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_6

6. The Extended Mind Thesis and Its Applications

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Abstract
A growing number of researchers claim that our traditional views about what cognitive processes are and where they take place must be revised. According to these researchers, the cognitive processes that make up our minds can reach beyond the traditionally conceived boundaries of individual organisms to include as proper parts aspects of the organism's physical, technological, and socio-cultural environment. This idea is known as the Extended Mind Thesis (EMT). In recent years, a fruitful debate about the scope and validity of EMT has emerged both within the empirical sciences (e.g., psychology and neuroscience) and in the philosophy of mind. The goal of this chapter is to investigate the empirical support for EMT by clarifying the extent to which researchers in philosophy, psychology, and neuroscience in their everyday work and practice already implicitly assume extended cognition ideas or even actively operate with them.

Keywords Human cognition – Extended mind theory – Cognitive science – Philosophy of mind – Memory – Vision and action – Language and gesture – Music

Introduction

A growing number of researchers claim that our traditional views about what cognitive processes are and where they take place must be revised. According to these researchers, the cognitive processes that make up our minds can reach beyond the traditionally conceived boundaries of individual organisms to include as proper parts aspects of the organism's physical, technological, and socio-cultural environment (Kiverstein et al., 2013, p. 1). This idea is known as the Extended Mind Thesis (EMT henceforth: Clark, 1997, 2008; Clark & Chalmers, 1998).

Proponents of EMT (Farina, 2020; Kiverstein & Farina, 2011, 2012; Menary, 2010; Rowlands, 2010; Sutton et al., 2010; Wheeler, 2010) typically hold that quite familiar human mental states (such as states of believing that so-and-so) can be realized, in part, by structures and processes located outside the human head. EMT thus paints the mind (or better, the physical machinery that realizes some of our cognitive processes and mental states) as, under humanly attainable conditions, extending beyond the bounds of skin and skull (Kiverstein et al., 2013).

The intellectual roots of EMT are rich and varied. One could argue that there are, at least, seven different fields or domains of research that have influenced the development of this theory. In this introductory section, we briefly review these domains and sketch out our plan for the chapter.

Work on Distributed Cognition

Distributed cognition (also see Hutchins, 2005) is the paradigm that describes cognition as a distributed phenomenon; that is, as occurring and taking place across objects, individuals, artifacts, and tools in an active environment. Distributed cognition takes place when two or more individuals engage in reciprocal interactions in order to solve some difficult cognitive tasks. To date, researchers working on distributed cognition have devoted much of their attention to

analyzing and describing the processes and properties of systems of actors interacting with each other and/or with an array of technological artifacts [such as airplane cockpits (Hutchins & Klausen, 1996), ship navigation (Hutchins, 1995), air traffic control (Halverson, 1995), and software teams (Ciancarini et al., 2021a, 2021b; Flor & Hutchins, 1991)]. Nevertheless, the most well-studied distributed cognitive systems are those involving transactive memory systems, where two or more individuals collaboratively store, encode, and retrieve information and knowledge (Wegner, 1987).

In highlighting the many ways in which brain, body, and world may work together in subtle technological, and often complex socially distributed and materially engaged partnerships, research on distributed cognition can be said to have inspired the development of EMT.

Work on Cybernetics and Connectionism

EMT was also inspired though, by early work in cybernetics (Ashby, 1956; Wiener, 1948). Cybernetics attempted to explain cognition in terms of circular causal chains, where some action produced by the system generated some change in its environment, which in turn triggered further changes in the architecture of the system. This work was crucial in inspiring research on EMT because it stressed the importance of feedback loops that run through the body into the world in explaining cognitive processes.

Connectionism is another crucial source of inspiration for researchers working on EMT. In denying that the vehicles of cognition are purely symbols encapsulated in the brain and in considering them instead as patterns of activation distributed across nodes in a network (Rumelhart & McClelland, 1986), connectionism (Clark & Karmiloff-Smith, 1993) has surely foregrounded important insights characterizing EMT, such as the idea that some of the mechanisms that underlie cognitive processes are not all in the cranium.

Work on Situated Robotics

Situated robotics is the study of robots embedded in complex, often dynamically changing environments. Situated robotics is based on the idea that intelligence is for doing things, and thus focuses on building

robots capable of displaying complex intelligent behaviors with little internal variable states to model (Brooks, 1991; Pfeifer et al., 2006). The idea is that robots are built with a repertoire of simple behaviors, which, when coupled and combined together via sensory motor links in a (largely) bottom-up fashion, can produce sophisticated actions and eventually cognitive processes (Clark, 1997). Among the most successful research programs in "situated" robotics developed to date are those led by Jun Tani at the Okinawa Institute of Science and Technology and by Dario Floreano at Lausanne. However, the most fascinating examples of situated robotics probably come from research conducted on humanoid robots (e.g., Atlas: Farina, 2020). These robots can perform complex actions (such as walking across rocky terrain, navigating hazardous surfaces, climbing stair steps), which clearly extend into the realm of the cognitive and involve—for instance—the development of a sense of proprioception (body conﬁguration), forms of attention, coordination, balance, and/or planning. Situated robotics inﬂuenced the formulation of some of the core principles of the extended mind thesis, such as the idea that cognition depends heavily upon the effects of a special kind of hybridization "in which human brains enter into an increasingly potent cascade of genuinely symbiotic relationships with knowledge-rich artifacts and technologies" (Clark, 2001, p. 1).

Work on Active Vision

Research on animate vision endorsed a view in which a perceiver uses her body and various other structures in the environment to offload perceptual processing onto the world. Gibson (1979) showed how visual perception is the result of a dynamic coupling between a perceiver that manipulates information-bearing structures and its environment. O'Regan and Noë (2001) further conﬁrmed this understanding of visual experience by focusing on the animated exploration of one's environment, thus displaying a sensitivity to sensorimotor contingencies in the environment of the organism. Ballard et al.'s (1999) animate vision paradigm within computation psychology experimentally demonstrated the deeply embodied and active nature of visual perception. Thus, in explaining the intentional and phenomenal characteristics of perceptual experience through the

appeal to sensory-motor dependencies (patterns of contingencies that hold between the movements the perceivers make and what they are able to perceive), work on animate vision (Churchland et al., 1994) provided important theoretical insights for many researchers working on EMT.

Work on Phenomenology

Equally important for the development of EMT was early work conducted in phenomenology. A crucial source of inspiration was Merleau-Ponty (2005), who proposed an embodied account of perception that challenged the dichotomy between mind and body envisaged by Descartes. Another crucial source of inspiration for EMT was Husserl (2005). It has been recently argued that Husserl's transcendental idealism has tight links with vehicle externalism (Zahavi, 2008)—the thesis that our mental states constitutively depend on items in the external world, which is at the core of EMT. Heidegger's existentialist phenomenology (1927) and, in particular, his concept of ***Dasein*** ("being there") was another influential source of inspiration for researchers working on the Extended Mind. ***Dasein*** is the idea that our minds should not be looked at as detached and passive, but rather as immersed in the world in which we live. In other words, according to Heidegger, we should study the world surrounding us as a system of relations in which we are practically involved and we should understand the mind not as a mere function of brain activity; rather, as emerging through interactive feedback loops between brain, body, and world (this is again a central principle underlying EMT).

Work on Material Culture

Works on cognitive ecologies and material culture also galvanized research on EMT (Knappett, 2011; Malafouris, 2004). Research on so-called cognitive artifacts, in the sense of "exograms" (Donald, 1991), "meshworks of things" (Ingold, 2010), "tools for thought" (Dennett, 1996), or "epistemic actions" (Kirsh & Maglio, 1994) demonstrated that things can have a cognitive life on their own, thus spurring proponents of EMT to develop the idea that cognition exists primarily as an enactive relation between and among people and things. The central notion underlying this line of research is the idea of material

engagement, a synergistic process involving material forms that people make/build, through which human cognitive and social life are mediated and often constituted. An example of material engagement is provided by culturally specific technologies that can be said to have constituted part of human cognitive architectures since, at least, the upper Paleolithic period (Donald, 1991).

Work on Cultural-Historical Psychology

Early work on cultural and developmental psychology conducted by Soviet researchers (most notably Luria, 1994; Vygotsky, 1987) was also critical for the development of some of the core ideas underlying EMT. This work showed how higher-level psychological processes could take place through the child's participation in socio-cultural activities and historical processes. The main idea of this influential line of research was that psychological abilities are produced (not necessarily inherited), and that the structure of these abilities mirrors the external structure of the actions concerning which one is engaged, often in collaborative interaction, with others. In brief, this is the idea that the mind is socially developed. This idea profoundly inspired research on EMT, especially research recently conducted on social cognition, which we review in the last section of this chapter.

This brief overview of the different strands of research that prompted and inspired the formulation and development of EMT demonstrates EMT's richness as a theoretical hypothesis, but also grounds it firmly in research conducted in the empirical sciences (e.g., neuroscience, psychology, cybernetics, biology, and robotics).

In what remains of this chapter, we look at the empirical support for EMT and clarify the extent to which researchers in philosophy, psychology, and neuroscience, in their everyday work and practice, already implicitly assume extended cognition ideas or even actively operate with them. In particular, in Section "The Extended Mind Thesis: Two Strands of Research", we introduce the principles and tenets underlying EMT and critically discuss two strands of research on EMT (parity-based and complementarity-based). This is done to provide a fuller understanding of the many facets of this theory. We subsequently review work in "traditional fields" (such as memory, vision and action, language and gesture) that shows how the principles and tenets of this

theory have inspired research in the cognitive sciences, thus attesting to the power of EMT as a research paradigm. We then review two major recent applications of EMT (in the field of social cognition and music perception) that further shows how productive these ideas can be for cognitive scientists and psychologists alike. We conclude this review chapter by arguing that EMT is a solid and mature research program with strong practical applications in the empirical sciences.

The Extended Mind Thesis: Two Strands of Research

EMT asserts that mental states and cognitive functions may sometimes supervene on organized systems of processes and mechanisms that criss-cross the boundaries of brain, body, and world. The crucial idea underlying EMT is therefore that some of our cognitive processes can and do actually extend outside of our heads. According to EMT, cognition does not exclusively take place inside the biological boundary of the individual but, on the contrary, can arise in the dynamical interplay between neural structures, body, and world. EMT claims that these pervasive, intimate, action-orienting, and behavior-guiding interactions result in external features that actively participate in an organism's mental activity, becoming functionally integrated in its cognitive superstructure. In other words, structures and processes located outside the human head can become, under certain conditions (known as glue and trust conditions), parts of the machinery that instantiates cognition. These conditions (the glue and trust conditions) were formulated in order to prevent the mind from spreading rampantly into the world and were offered as requirements needed for an external resource to effectively count as part of the mind. The glue and trust conditions say that an external resource counts as part of our mind only if it is (1) portable, (2) easily accessed, and (3) automatically endorsed (reliable). As Sutton put it: "external systems and other cognitive artifacts are not always simply commodities, for the use and profit of the active mind: rather, in certain circumstances, along with the brain and body which interacts with them, they are the mind" (Sutton, 2010, p. 190).

EMT is often depicted as ﬂowing naturally from functionalist views concerning the "multiple realizability" of cognitive processes (Wheeler, 2010), and indeed one strand of argument for EMT invokes the so-called "parity principle" (PP henceforth). This argument is exempliﬁed by the famous case of Otto and Inga, introduced by Clark and Chalmers (1998), which we discuss next.

Inga, a healthy subject, hears about a new exhibition at the Museum of Modern Art in New York and realizes that she wishes to see it. Upon hearing this information, Inga uses her biological memory to form or retrieve the belief that MoMA is on 53rd street, and makes her way downtown. At the same time, Otto hears about the very same exhibition. He also likes the exhibition's theme and decides to visit it. Unfortunately, Otto suffers from Alzheimer's disease. His medical condition prevents Otto from reliably using his biological memory to form or retrieve the belief that MoMA is on 53rd street. However, as a compensatory strategy, Otto has learned to rely upon a notebook, in which he writes all the stuff he can no longer remember with his brain. Otto always keeps his notebook ready to hand, so that when he needs it, he can smoothly retrieve the crucial information from it. In the case at stake here, Otto uses the notebook to retrieve information about the location of MoMA and then sets off.

Clark and Chalmers (1998) ask their readers to compare the cases of Otto and Inga and invite them to reﬂect on whether they should attribute to both Otto and Inga a standing belief about the physical location of New York's MoMA. Clark and Chalmers (1998) believe that "the information contained in Otto's notebook plays the same causal role in guiding his actions as Inga's biological memory does in the guidance of her actions" (Kiverstein & Farina, 2011, p. 37). For this reason, they count Otto's notebook as part of the causal machinery that instantiates his standing beliefs. We should not treat Otto's case differently from Inga's case, they argue, just because the states that drive Otto's behavior are partly ofloaded onto the environment and therefore located outside of Otto's physical boundary. This is the thought that stands behind PP, which runs as follows:

> If, as we confront some task, a part of the world functions as a process which, were it done in the head, we would have no

> hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process (Clark & Chalmers, 1998, p. 2).

PP thus invites us to assess whether a state can count as a belief, in part, on the basis of the causal role it performs. For Clark and Chalmers (1998), it does not really matter where the lodger of this causal role is housed. It can be located within the confines of the biological body, or rather span the brain, body, and world. What makes something a belief is for them a matter of the causal relations that this lodger entertains to inputs and outputs and to other mental states. In other words, Clark and Chalmers (1998) do not believe that the physical details of a state that stands in these causal relations can matter when it comes to decide whether the very same state counts as a belief or not.

Besides this functionalist approach to EMT, a second strand of research (equally important) has been recently developed. This second strand emphasizes considerations of "complementarity." Complementarity approaches (Sutton, 2010) investigate the many different ways in which diverse components (neural and extra-neural) of a cognitive system intermingle and function together in forging a novel unit of cognitive analysis and complex cognitive behaviors that would not otherwise be experienced by the user's brain on its own (Farina, 2019). This understanding of EMT entails that outer states or processes need not to replicate the functions and the roles of internal biological ones, but rather that different components of a cognitive system can coalesce and reciprocally intermingle in the production of flexible cognitive behavior.

In truth, complementarity themes can be found in Clark's seminal work (1997). In "***Being There***" (1997), Clark highlights the crucial transformative power of artworks, pieces of technology, media, social networks, and institutions for human cognitive behavior, while illustrating the frequency with which we rely, in rich and interactive ways, on the capacities of specific non-biological features. These extra-cranial features are, Clark (1997) argues, quite often "alien but complementary to the brain's style of storage and computation. The brain need not waste its time replicating such capacities. Rather, it must learn to interface with them in ways that maximally exploit their

peculiar virtues" (Clark, 1997, p. 220). Thus, rather than causally aiding the production of cognitive behaviors, these complementary, non-biological/extra-neural factors become "equal (though different) partners in coordinated, coupled larger cognitive systems" (Sutton, 2010, p. 524).

Elsewhere, Clark (2003; 1997, p. 99) further reinforced the idea that external factors can have an impact in multiple and signiﬁcant ways upon our biology, so as to create augmented systems whose cognitive power goes well beyond that of the naked brain alone. Complementarity is thus clearly a key theme or a trademark label of his own work. Here, however, it seems fair to do a bit more citation and crediting. While standard Complementarity themes are peculiar to Clark's seminal works and can also be found in earlier treatments [such as Rowlands (1999) for instance] harking back to and building on Wilson (1994) and Haugeland (1998), the idea of picking out Complementarity as a clear alternative route to EMT that differs from parity should be ascribed to Sutton (2002, 2006, 2010), whose treatment has subsequently forged the basis for Menary's defense of extended cognition based on the idea of cognitive integration (Menary, 2007). Complementarity has also recently become a central theme in Rowlands (2010). For a more technical overview of these issues, please refer to Farina (2020).

Having brieﬂy discussed the two strands of research that characterize EMT, and therefore having better understood the many facets of this theory, we now turn to brieﬂy review some research in the empirical sciences that is consistent with these ideas. The goal of this brief review is to demonstrate that EMT is a solid and mature theory of cognition. In other words, EMT is not just a philosophical mantra empty of empirical contents.

Memory

As Sutton (2006) noticed, an alliance has been forged between memory research in cognitive psychology and the independent set of ideas in theoretical cognitive science labelled as the "extended mind" hypothesis. This alliance has produced an original understanding of the process of reminiscing, which is nowadays often described as an

inferential process that is constructive and creative in character, rather than merely reproductive. In recent years, as a result of this strong alliance, a number of memory theorists (Sutton, 2006; Tribble, 2005) have begun treating the vehicles of representation in memory as well as the processes underlying remembering itself as effectively spreading across brain, body, and world. More precisely, extended theorists of memory have argued that stable storage of information over time is, in many cases, only possible against the backdrop of a social context and achievable through the integration of biological and external materials (such as symbolic, technological, and cultural artifacts). As Sutton put it: "mnemonic stability is often supported by heterogenous external resources as well as, and in complementary interaction with, neural resources" (Sutton & Windhorst, 2009, p. 229).

In this research field, EMT has therefore represented a crucial source of inspiration for many researchers. Rowlands (1999), for instance, using the conceptual palette afforded by EMT, argued that at least some memory processes must be understood as the result of a series of interactions between a remembering organism and its environment. On this basis, he claimed that working memory must be described as "hybrid" in character (similar claims have been made by Wilson, 2005). However, EMT was also profoundly shaped by the everyday practice of memory theorists, who provided new powerful insights for its own development. In what follows, we briefly summarize research that highlights the two points introduced in this paragraph.

Let us start with the former, which is about how the principles and tenets underlying EMT have inspired the works of philosophers, anthropologists, and psychologists in memory studies, especially with respect to social interactions (Nelson & Fivush, 2004), augmented memories (Donald, 1991), and collaborative recall (Fivush & Nelson, 2006; Sutton et al., 2010; Tollefsen, 2006; Tribble, 2005).

Nelson and Fivush (2004), two of the major contemporary proponents of the socio-cultural developmental theory of memory, described the emergence of autobiographical memories (episodic and semantic recollections from an individual's life) as the product of a socio-cultural cognitive system "wherein different components are being opened to experiences over time, wherein experiences vary over

time and context, and wherein individual histories determine how social and cognitive sources are combined in varying ways" (p. 487). The idea is thus that autobiographical memory is a cultural activity specific to the individual and the society from which it is shaped.

> The ability to create an autobiography, a personal history of self that is continuous in time, with specific events experienced at particular points and linked both to each other and the present, is a complex human skill that relies on multiple component developmental skills, including the development of subjective consciousness, the developing ability to link past self to present self, and the developing ability to construct a personal time (Fivush, 2011, p. 561).

Autobiographical memory, according to Fivush (2011), must therefore be understood as a complex ability with a long developmental history that encompasses both phylogenetic (diachronic) and ontogenetic (synchronic) contributions. It is precisely this link with the ontogenetic level that offers a strong connection with EMT, as EMT is—largely—a theory of cognition that studies the synchronic interrelations between an individuals' brain and body and his/her own surrounding environment, focusing on the ongoing interactive dance between brain and world through which, by forms of "continuous reciprocal causation," adaptive action results (Clark, 1997, pp. 163–166).

Donald (1991) also studied the changes to human memory that resulted from the spread of external symbolic representations (exograms) in order to explain how the storage capacity of humans' biological memory systems became enhanced throughout human cultural evolution. According to Donald (1991), "exograms" allowed humans to augment their working memory capacity by manipulating complex representations that shaped the biophysical and biochemical functioning of their internal biological memory storage system (what Donald calls "engrams"). This thereby created distributed hybrid networks of memories that dramatically transformed our cognitive profile, allowing us to retain crucial information more safely over time than our fragile biological memories could. The link between this

research and research on EMT is, again, quite evident, and it relies on the idea of enhancing cognitive processes (memories in this case) through socially engaged and distributed partnerships with rich socio-cultural environments. Yet, the subfield of memory studies, where research on extended cognition has probably exerted the maximum influence, is the study of collaborative recall.

Tribble (2005) investigated how actors in early modern theater were able to meet the challenge of performing an astounding number of plays every week by exploiting the social and physical scaffolding of their environments; that is, by relying on the interplay of biological recall, specially engineered spaces, and clever socio-cultural practices. In a fascinating study, Tollefsen (2006) further explored the space of interaction between memory, social ontology, and extended cognition. In particular, Tollefsen (2006) focused on socially distributed transactive memory and used experimental work on collective recall to explain the formation of intentional and epistemic properties in groups of individuals (Kiverstein et al., 2013). In brief, to explain the emergence of group (collective) minds, Fivush (2007) also tested the claim that reminiscing is an intrinsically social activity and looked specifically at how mothers engage in reminiscing with their kids. Fivush (2007) found out that highly elaborative mothers who engage in long conversations about the past with their kids usually have children who are able to tell more emotionally expressive narratives, to display a better understanding of the self, and to produce more elaborated memories of their past than children whose mothers were not as elaborative.

All of the studies reviewed in this section show how principles and tenets underlying research on EMT (such as the idea of synchronic interactions among individuals, augmented memory capacity developed through proactive collaborations or partnerships with external props) inspired, and to some extent even guided and directed, the practice of many memory theorists. However, we should also acknowledge that research on EMT was, in turn, deeply influenced by work carried out in memory studies. Sutton et al. (2010), for instance, offered a detailed, multidimensional account of collaborative recall in older couples, which demonstrated how collaboration may facilitate or hinder memory among dyads of married individuals. This account was

used to articulate and further develop research on the second strand of EMT—complementarity-based, which we discussed earlier on in Section “The Extended Mind Thesis: Two Strands of Research” above—which supports an extended and socially distributed view of memory and cognition.

Having reviewed works in the field of memory studies that clearly showcases the heuristic value of EMT in the field, we next turn to analyzing research in another important domain (vision and action), where such heuristic value is also quite evident.

Vision and Action

A substantial body of research on so-called animate vision (Ballard et al., 1997; Churchland et al., 1994) has proven the embodied and active nature of visual perception. Works on animate vision rejected what Churchland et al. (1994) dubbed the paradigm of pure vision, “the idea that vision is largely a means of creating a world model rich enough to let us throw the world away” (Clark, 1999, p. 345), and by contrast, gave action a starring role. Vision, Churchland and colleagues write, “has its evolutionary rationale rooted in improved motor control” (Churchland et al., 1994, p. 25). Research on animate vision thus endorsed a view in which a perceiver uses her body and various other structures in the environment to offload perceptual processing onto the world (Farina, 2020, p.81).

As an illustration of this point, consider next Dana Ballard’s work. Ballard et al. (1997) performed a series of experiments, which demonstrated how saccades (eye movements) could be used to access task-relevant information in the world. This work demonstrated that in order to avoid maintaining and updating costly, enduring, and detailed internal models of our visual surroundings, we normally end up sampling the environment in ways suited to the particular needs of the moment’ (Farina, 2020, p. 81). Rowlands (2006) offered a fascinating account of normative actions (which he calls deeds) that is independent of any connection to prior intentional states (thus attuned to EMT), and argued that the saccadic deeds involved in certain acquired, skilled movements—such as cricket batting—have a function that is deeply rooted in the individual and collective history of

the skillful practice in question. Hurley (2001) also defended an extended account of visual perception in which real-time, action-oriented physical interactions with the surrounding environment are necessary for furnishing the content of visual experience. Likewise, Noë (2004) famously argued that visual perception is not something that happens to us, or in us; rather, it is something that we do. In other words, perceptual experiences ultimately depend on capacities for action and thought, and vision is a kind of skillful activity involving the body as a whole.

More recently, this approach to vision has been further developed by Lauwereyns (2012), in sharp critical reference to Marr and Poggio's computational account of vision (1979). His "intensive approach to vision is a combination of classic computational theories of perception (a là Marr, 1982) that say that vision is essentially a top-down process, and less conservative accounts (a là Noë, 2004) that emphasize the pervasive sensorimotor nature of perceptual experience and the role that (bottom-up) sensorimotor engagements play in visual processes" (Farina, 2013a, p. 1036).

Summing up, we can thus say that nowadays vision is widely understood (Parr & Friston, 2017) to be an activity in which a perceiver actively uses various structures in the environment to offload cognitive processing onto the world and to determine the content of her experience. Vision is thus fundamentally tied to motor representations (Bruineberg et al., 2016; Zimmermann & Lappe, 2016).

Research on sensory substitution devices (SSDs) represents a very nice example of how some of the basic principles underlying work on EMT are expressed in the field of vision and action. The term "sensory substitution" refers to the use of a sensory modality to supply environmental information normally gathered by another sense (Farina, 2019). Sensory substitution devices (SSDs) thus provide through one sensory modality (the substituting modality) access to features of the world that are generally experienced through another sensory modality (the substituted modality). There are two main classes or categories of SSDs. These are: visual-to-auditory systems [such as the vOICe] that translate visual images taken by a video camera into auditory soundscapes, and visual-to-tactile sensory substitution devices [such as the Brain Port] that translate visual

inputs into vibrotactile stimulation. Much of the philosophical debate surrounding SSDs has been characterized by the attempt to individuate which sensory modalities the use of these modalities trigger, and whether the coupling between the impaired users and these devices can augment the users' cognitive abilities (Macpherson, 2018; Matthen, 2015).

Auvray and Myin (2009) argued that SSD use triggers in proficient users the acquisition of a new sensory modality, which is complementary to those standardly recruited. Kiverstein et al. (2015) echoed this understanding and pointed out that persistent SSD usage delivers a new mode of perception that is not reducible to that of any single existing sense or any combinations of existing senses. Instead, under certain circumstances, a given cortical brain region—e.g., sensory cortex—can exhibit functional plasticity and support novel perceptual processing irrespective of the nature of the sensory inputs that are being sent to it. Farina (2013b) and Auvray and Farina (2017) agreed that the coupling between the user and the device may trigger an entirely new sensory modality but reflected on whether this new modality may count as a form of artificially induced synesthesia. Finally, Kiverstein and Farina (2012) studied the partnership between the user and the SSD, and argued that it enables cognitive transformations that gradually allow the device to become fully transparent and be part of the machinery that instantiates cognition, leading the user to experience new phenomenal occurrences.

Complementarity approaches (Clark, 1997; Sutton, 2010), as we have seen before, investigate the many different ways in which diverse components (neural and extra-neural) of a cognitive system intermingle and function together in forging a novel unit of cognitive analysis and complex cognitive behaviors that would not otherwise be experienced by the user's brain on its own. Research on SSDs clearly provides important empirical applications for this set of ideas. SSDs, in providing their experienced users with a new phenomenal way of accessing the world, become a paradigmatic example of cognitive augmentation and contribute to create a new space of biotechnological synthesis between the user, the device, and the world in which it is used (incorporation and transparency take place).

Having briefly explored the points of connection between research on EMT and work in the empirical sciences in the field of vision and action, we can now turn to investigate how EMT can be used to shed some light on the relationship between language and gesture.

Language and Gesture

Language and Gesture are two fields in which research on EMT has proven to be a good source of inspiration for many researchers and where the principles underlying it have been consistently and successfully applied. We discuss these two fields in this section separately, starting with language.

Work on the extended mind (e.g., Clark & Thornton, 1997) describes language as a kind of meta-tool enabling a variety of cognitive extensions. Clark (2006), for instance, argued that language (understood as a public tool) not only gives us opportunities for communicating our thoughts, but can also be used to enhance our cognitive skills [an understanding also echoed by (Dennett, 1984)]. This particular understanding of language has been quite influential both within philosophy and in the empirical sciences. For instance, Boysen et al. (1996) showed how chimpanzees can be trained to use symbol tokens to decompose high-level cognitive tasks into simple pattern matching tasks, which they then could easily solve. Deacon (1997) developed an influential theory of language that asserts that our capacity for abstract thought, logical reasoning, and compositionally structured, counterfactual thinking is invariably dependent on public language, which is the tool that ultimately allowed the evolution of our minds (Kiverstein et al., 2013).

In a similar vein, Clark (1996) claimed that language is a joint activity, involving individual and social processes, that emerges when listeners and speakers perform their action "in ensembles," as a single cognitive unit of analysis. Language can thus be considered (in accordance with the principles underlying EMT) as a heterogeneous set of physical, cognitive, and socio-cultural activities unfolding in real-time across multiple time-scales, which can be viewed as a sort of augmenting property (Spurrett & Cowley, 2004) that emerges when we

begin coordinating our life worlds with each other, behaviorally and cognitively (Cowley & Spurrett, 2003).

Language, however, often relies on gestures. Gestures can map different meanings—often more effectively—than language (Jamalian et al., 2013). In addition, gestures can help an audience to understand a message, by showing the transformation of ideas and relations between one thought and the next (Chu & Kita, 2011). Furthermore, gestures can also help formulate thoughts and augment comprehension and learning capabilities (Chu & Kita, 2011; Jamalian et al., 2013; Kang et al., 2012).

Clark (2008) extensively discussed the role of gestures in cognition. In particular, he defended the idea that gestures, at least on some occasions, may count as an example of a non-neural activity that becomes part of the machinery that instantiates intra-personal thinking and higher-level reasoning. The claim that gestures play a similarly constitutive role in inter-personal cognitive engagement and thus the idea that they may perform a crucially important expressive role in human communication, becoming themselves constitutive parts of the process underlying human thought has also been endorsed by other researchers, among them cognitive scientists, anthropologists, and even psychologists (Alač & Hutchins, 2004; Hutchins, 1995; Latour, 1984; McNeill, 2005; Radman, 2013). For instance, in a fascinating paper inspired by Clark's seminal work (1997), Alač and Hutchins (2004) discussed an example of how gestures can become vehicles of mental states in intersubjective interactions. The example involves' an expert scientist interacting with a novice with the aim of teaching her how to grasp the meaning of complex FMRI scans. Alač and Hutchins (2004) show that the gestures performed by the expert are instrumental, constitutive components in the process of teaching the novice scientist how to rightly understand and grasp the meaning of certain structures in brain scans' (Ciancarini et al., 2021a, p.71945) (see Gangopadhyay, 2011 for a detailed discussion of this experiment).

This is thus a case where the gestures performed by the more experienced group member enabled the less experienced one to acquire a fundamental cognitive skill, and therefore quite clearly demonstrates how gestures (an example of a non-neural activity) can

profoundly shape the learning of a cognitive skill (learning to see certain patterns in FMRI images). So, gestures can definitely assist the learning process by scaffolding understanding into more advanced stages of cognitive competence (Krueger, 2013, p. 42). It has also been demonstrated that students who mirror teachers' gestures learn quicker and more effectively than those who do not (Cook & Goldin-Meadow, 2006). This is because gestures are often used to guide someone's attention and to represent both actions and ideas (Becvar et al., 2008). Another example of how gestures can become constitutive of certain cognitive abilities is offered by Cappuccio et al., who investigated how pointing (which is a type of gesture) becomes instrumental and thus constitutive for representing geometrical information concerning one's own gaze direction. Finally, Goldin-Meadow and Singer (2003) also studied how gestural movements not only help us to express our thoughts, but also play an essential role in teaching concepts and ideas.

The work on language and gestures reviewed in this section shows how the principles of EMT (such as the idea of language as an augmenting property arising in real-time interactions across multiple timescales from a different set of physical, cognitive, and socio-cultural activities, or the understanding of gestures as enhancing comprehension and learning capabilities) have inspired—in important ways—research in these two domains, further attesting to EMT's positive heuristic value.

Having drawn some important connections between EMT and three major domains of research (memory, vision and action, language and gestures), where the principles underlying EMT have been applied, we next review two more major recent applications of EMT (in the field of social cognition and music perception) that further attest how influential these ideas can be for philosophers, social psychologists, and cognitive scientists. The goal of the following discussion, besides showing that EMT is a solid research program, is also to broaden the debate beyond the traditional fields and thus to demonstrate how these "theoretical" considerations can ramify in the wider world.

Two Recent Developments

Social Cognition

A number of researchers have attempted to apply some of the principles underlying research on EMT to the domain of social cognition (Fuchs & De Jaegher, 2009; Gallagher, 2013; Gallagher & Crisafi, 2009), developing a new line of research (the so-called Socially Extended Mind), which claims that the mind is not only extended in the physical environment but also in enactive engagements with the social milieu. The idea underlying this line of research is therefore that social cognition is not fully reducible to the workings of individual cognitive mechanisms and that socially interactive—or distributed processes—can often complement and even replace them.

The first paper that made this point clear was written by Gallagher and Crisafi (2009), who argued that institutions (such as legal systems, educational systems, or cultural organizations like museums) are often the expression of minds that are externalized and extended into the world. According to the authors, these institutions are "mental institutions" because they help us accomplish sophisticated cognitive tasks that as individuals would not be able to accomplish. The basic idea here is therefore that the cognitive processes characterizing these institutions do not necessarily happen in individual brains; quite the opposite, they occur in socially structured interactions that are made possible by the very existence of these "mental institutions." Building on this idea, Gallagher (2013) further claimed that social-institutional practices allow those who are capable of acting through them to extend their mind socially, both in terms of vehicles and contents.

The question about the possibility of social mental extension, based on considerations about the status of groups of people acting together, was also central to Theiner et al. (2010), who claimed "that groups have organization-dependent cognitive capacities that go beyond the simple aggregation of the cognitive capacities of individuals" (p.378). Ludwig (2017) critically investigated the collective minds hypothesis we described—the possibility that an institutional system of cognitive processes could be considered as a cognitive agent—and provided an interesting challenge to the idea of a socially extended mind by showing that we ought not to treat corporations or institutions as cognitive agents because socially situated minds do not necessarily give rise to collective minds (the

reason, on his view, is that the mechanisms and processes that characterize socially salient forms of mental activity are traits of individuals not of groups). More recently, in disagreement with Ludwig (2017), Gallotti and Huebner (2017) framed this work on extended minds within the broader conceptual palette afforded by research on socially distributed cognition. In particular, the authors defended a view that emphasizes the ineliminable social dimension of individual minds. Finally, Lyre (2018) studied the mechanisms of shared intentionality in human beings and argued "that they can too be considered as coupling mechanisms of cognitive extension into the social domain" (p.831).

The field of extended social cognition is relatively young (about 10 years old) and also very fluid. Yet, from the brief review we conducted in this section, it can be seen that ideas underlying this research (such as the idea of mental institutions defended by Gallagher, 2013) have been inspired by tenets and principles of EMT. In addition, this work on socially extended minds stresses the instrumental role of non-neural factors (in this case, mental institutions) in forging novel cognitive and social abilities. As such, we can assert that this work is strongly attuned with the complementarity version of EMT we described earlier on.

Having looked at how ideas underlying EMT are inspiring research in the field of social cognition, we next turn to analyze another field where EMT has exerted extraordinary influence: the field of music cognition.

Music Cognition

To date, three major accounts of music cognition, inspired by EMT, have been developed. These are (a) Cochrane's "expression and extended cognition" (2008); (b) Krueger's (2014, 2015) "musically extended emotional mind"; and (c) Kersten's "extended computational view of music cognition" (2015, 2017).

In truth, though, some of the ideas characterizing these accounts, and therefore underlying EMT, can be found in Clarke's seminal work (2005), which proposed an ecological approach to music perception. Clarke, in particular, investigated the relationship between music, motion, and subjectivity, and stressed the importance of understanding

music as a relationship between active perceivers and rich, highly scaffoldable environments.

However, the first proper account of extended music perception was effectively proposed by Cochrane (2008), who argued (i) that music is a cognitively extended process and (ii) that musicians often use music to enhance the formation of their emotional states (Cochrane, 2008, p. 335). The idea underlying Cochrane's proposal is that the artistic medium (the particular musical instrument) used by the musician allows her to manipulate the music, thus extending her cognitive repertoire and enabling the creation and production of new musical pieces. This allows the musician, on Cochrane's view, to reflect and elaborate her emotional states, so that eventually the musical experience replaces the body as the central focus of the emotional content.

Building on Cochrane's seminal account, Kruger (2014) argued that music is a mighty environmental resource for extending our emotions. On the basis of a series of neuroimaging studies, which showed that our emotional responses to music trigger and activate brain structures involved in generating, detecting, maintaining, and regulating emotions (Koelsch, 2014; Overy & Molnar-Szakacs, 2009), Kruger claimed that music perception and emotion experience are closely coupled processes (Krueger, 2014). He writes: "[M]usical affordances provide resources and feedback that loop back onto us and, in doing so, enhance the functional complexity of various motor, attentional, and regulative capacities responsible for generating and sustaining emotional experiences. It is thus sensible to speak of the musically extended (emotional) mind" (Krueger, 2014, p. 4). The idea is therefore that music through its auditory affordances can intensify our social experiences and—in regulating our emotions—can also alter our behaviors.

This research, in emphasizing the role of affordances and the complementary contributions of the environment to music perception and experience, was clearly inspired by the complementarity-based approach to EMT that we discussed earlier on. However, not all research in the field of music cognition can be said to draw from complementarity considerations. Some researchers have stressed the profound link between the functionalist (computationalist-based) view

of EMT and music perception. In particular, an account of music perception based on the functionalist strand of research was recently proposed by Kersten (2015, 2017).

Music, in his view, is an extended phenomenon, but one in which the enacted relation with emotional states of the musicians is not so crucial. What is crucial, on Kersten's account, is instead the computational and information-processing nature of music perception. The idea is thus that music perception can be understood in light of the wide computationalist framework developed by Wilson (1994), which is the view that asserts that at least some of the unit of a computational system reside outside of the individual. There are, of course, certain conditions that a wide computational cognitive system must fulfil, according to Wilson (1994). We do not have the space to review these conditions here but suffice to say that Kersten, in his papers (2015, 2017), demonstrates that these conditions are fully satisfied and, on these grounds, goes on to substantiate his wide computationalist approach to music perception.

In this section, we reviewed recent work on socially extended cognition and extended music perception and showed how this work was inspired by different strands of research underlying EMT. Next, we draw a short conclusion, summarizing what we have achieved so far, and point to some limitations affecting the theory.

Conclusion

In this chapter, we looked at how EMT inspired several lines of research in philosophy and the cognitive sciences. We reviewed empirical support for EMT and clarified the extent to which researchers in the empirical sciences have sometimes used principles and tenets underlying EMT to further their research. We also looked at how this has sometimes influenced the development of EMT itself.

Of course, EMT has crucial, important limitations, and we do not believe that it can be meaningfully used to explaining all sort of phenomena in cognitive psychology. There are indeed some areas or domains (such as concepts and prototypes, priming effects, word frequency, sentence processing, and possibly face perception), in which EMT will probably not be particularly helpful to psychologists. Yet, after

reviewing all of these studies, the modest conclusion that this review chapter wants to make (and that should at this point be evident to our reader) is that EMT is a solid and mature research program with strong practical applications in the empirical sciences, whose importance stretches far beyond the philosophical arena into the wider society.

Acknowledgements

The writing of this chapter was supported by RFBR (Project No. 18-311-20004). Mirko Farina expresses his appreciation to the British Academy for the Humanities and Social Sciences, to King's College London, and to Innopolis University for generously supporting his research. Thanks also to the editors of the volume, to Andrea Lavazza, Russ Shafer-Landau, John Sutton, Andy Clark, Julian Kiverstein, and to the two anonymous reviewers for helpful comments on earlier drafts of this manuscript.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_7

7. Measuring the Mathematical Mind: Embodied Evidence from Motor Resonance, Negative Numbers, Calculation Biases, and Emotional Priming

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Abstract
Embodied cognition opposes the view of the mind as a computer. It is therefore diagnostic to assess how our bodies contribute to our computations—i.e., to numerical cognition. We begin by pointing out how embodied cognition changed our methodological focus from button-pressing to movement analyses. Then we review our recent work on how the pervasive association between numbers and space influences number-related tasks, beginning with single-digit processing and comprehending negative numbers. These studies address the challenge to embodied cognition from using abstract concepts and also introduce the promising grip-force methodology. Next, we describe how grounded, embodied, and situated knowledge representations impose systematic heuristics and biases on mental

arithmetic. A new model explains how we activate our motor system while calculating. Finally, we document how emotional processing interacts with calculating and identify cross-domain cognitive principles. This work converges on supporting an embodied understanding of the mathematical mind.

Keywords Embodied arithmetic – Emotions – Grip force – Heuristics and biases – Negative numbers – SNARC – Spatial-numerical associations

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Measuring the Mathematical Mind: Embodied Evidence from Motor Resonance, Negative Numbers, Calculation Biases, and Emotional Priming

Today's intense interest in embodied cognition has several origins. First among them is a profound inability of traditional views of knowledge representation to explain how we understand the meaning of symbols. Searle (1980) powerfully illustrated this shortcoming of traditional theories of human cognition with his Chinese Room example. This example clarified that systematic and rule-abiding symbol manipulation alone is not sufficient evidence for symbol comprehension. For example, responding with "bachelor" when reading in a crossword puzzle "adult unmarried male", or replying "4" in response to "how much is 3 + 1?" cannot be explained by the mere spreading of activation between propositional nodes in mental knowledge networks. Rule-abiding symbol transformations can occur without meaning comprehension. This so-called "grounding problem" for traditional theories of cognition (Harnad, 1990) called for richer representational theories in which cortical activations for different concepts are not merely related to other "defining" representations in a conceptual network, but instead to distinct sensory and motor activity patterns, through which meaning is constituted (e.g., Barsalou, 2008; Fischer & Coello, 2016; Pulvermüller et al., 2014).

Other dissatisfactions with the traditional cognitivist approach to the human mind as a computing device also support today's embodied

re-conceptualization of cognition. For example, there had been a long-standing discontent with the counter-intuitive focus on button pressing behavior in laboratory studies whose declared goal was to advance psychology, defined as the science of human behavior and experience (Rosenbaum, 2005). Clearly, cognition is both informed by and performed for meaningful actions. This functional stance on cognition has inspired an ever closer look at the cognitive content of the motor system, and with it a special role for spatial representations and processes in all of cognition (Bergen, 2012; Gianelli & Fischer, 2016; Rosenbaum, 1991/2010).

Gradual insights into the many theoretical and practical advantages of an embodied understanding of cognition show that the time is ripe to challenge one of the remaining "fortresses" of traditional cognitive theorizing. The once-popular analogy of the human mind as a computer was driven by the idea that mental computing or "numerical cognition" itself is an example par excellence for the view that cognition is nothing but abstract and rule-based symbol manipulation (e.g., Groen & Parkman, 1972). If this were true, then we could properly understand the human mind at the computational level without recourse to its physical implementation (Marr, 1980). The empirical evidence to be reviewed below challenges this analytical stance and instead exempli fies that computations in our minds are action simulations, constrained by our bodies and consistent with an embodied understanding of cognition.

A hierarchical conceptual framework for the study of embodied cognition in the domain of number knowledge (and beyond) distinguishes three levels of knowledge representation: Grounding, embodiment, and situatedness (Fischer, 2012; Fischer & Brugger, 2011; Myachykov et al., 2014; Pezzulo et al., 2013). The first level, ***grounding***, acknowledges fundamental constraints imposed on cognition from the physical world and the evolutionary history of the mind. This refers to the structure of our nervous system with its sensory and motor capacities, as well as to physical laws such as gravity or the fact that different objects must occupy different places. Grounding of cognition explains why mental rotation resembles physical rotation, including bodily constraints (Parsons, 1994), or why "more is up" is a universal metaphor re fecting object accumulation (Lakoff & Johnson, 1980).

The second level of knowledge representation refers to sensory-motor experiences and encompasses ***embodiment*** proper. Its focus on associative learning experiences and encompasses individual differences in spatial-conceptual associations (Casasanto, 2009, 2011), including effects on numerical cognition from finger counting habits (Fischer, 2008; Roesch & Moeller, 2015; for more details, see below).

Finally, knowledge is ***situated*** in the sense that it is strongly influenced by current task constraints, objectives, and intentions (Robbins & Aydede, 2007; Wilson, 2002). This can rapidly change behavioral signatures of embodiment, including the spatial contextualization of number concepts (e.g., Fischer et al., 2009, 2010). We will return to the merits of this hierarchical approach to cognition at the end of this chapter.

Numbers as Abstract Concepts

At first glance, numbers are seemingly simple symbols; but they also raise a challenging research question for cognitive scientists: On the one hand, number concepts are closely related to specific real-life experiences in their use, such as directing tourists to a bus with a specific destination ("bus number 2"; ***nominal*** number meaning), awarding places on a score sheet to sprinters ("second place"; ***ordinal*** number meaning) or establishing set sizes for objects ("two eggs"; ***cardinal*** number meaning). On the other hand, the numbers themselves are intrinsically abstract in their meaning, as it is precisely their flexible application that prevents anything tangible in the real world to consistently correspond to a number "2" or "3", as it does to concrete concepts such as "bus", "runner-up" or "egg". Traditionally, proper knowledge about number meanings and the rules for manipulation has been described without systematic recourse to specific behaviors, such as moving a pointer along a number line or finger counting (e.g., Frege, 1884; Russell, 1931). Later philosophical positions instead identified the meaning of concepts, including number concepts, through their use (e.g., Wittgenstein, 1953).

Most proponents of today's embodied cognition stance claim that all knowledge remains associated with those sensory-motor experiences that accompanied its initial acquisition and further use. It

is through retrieval of these associative sensory and motor features that all concepts receive their meaning, and this meaning-making mechanism applies to abstract as well as concrete concepts (e.g., Barsalou, 1999, 2008; Fischer & Shaki, 2018). Thus, it is time to consider how sensory-motor activity relates to and supports the creation of number concepts. Three specific proposals for such mechanisms are: the mental number line metaphor, a theory of magnitude, and the finger counting hypothesis. Let us briefly introduce each of them in turn before we discuss recent evidence from our own lab, the Potsdam Embodied Cognition Group.

Mental Number Line (MNL) Metaphor

The MNL metaphor for number knowledge suggests that numbers are cognitively represented with inherently spatial associations, namely on a horizontal line with larger numbers to the right of smaller numbers (cf. Dehaene, 2011, Chap. 3). This representation is presumably a result of directional spatial experiences, such as reading or viewing graphic depictions of number intervals. Most of the experimental support for this proposal comes from research on the ***SNARC effect***—an acronym for ***Spatial Numerical Associations of Response Codes***. In a wide range of number-related tasks (e.g., speeded parity judgments: "Is this number odd or even?"; or magnitude classifications: "Is this number smaller or larger than 5?"), participants are faster and more accurate when responding to smaller numbers in the stimulus set (e.g., 1 or 2) with a left-sided response compared to a right-sided response; the opposite is true for large numbers (e.g., 8 or 9), which are instead associated with right-sided responses (Dehaene et al., 1993; for reviews see Fischer & Shaki, 2014; Toomarian & Hubbard, 2018; Wood et al., 2008). This spatial-numerical association is indeed culturally shaped in adults (Bächtold et al., 1998; Fischer et al., 2009, 2010; Shaki et al., 2009), but also seems to reflect innate predispositions (De Hevia et al., 2017; Di Giorgio et al., 2019; Felisatti et al., 2020a, b). Thus, like most signatures of embodied cognition, the spatial-numerical association is best understood as a compound effect, composed of evolutionarily inherited constraints, a long-standing sensory-motor learning history, and task-specific demands.

The MNL account of embodied number representation encompasses not only natural numbers but perhaps also negative numbers (as an extension of the MNL to numbers less than zero, see Mende et al., 2018). The MNL can even be applied to understand mental arithmetic operations with shifts on the MNL to the left or to the right for subtractions and additions, respectively. We will turn to these possible extensions of the MNL account below.

Proposal of a Theory of Magnitude

The second proposal for embodied number concepts is a Theory of Magnitude that was originally developed by a cognitive neuroscientist (Walsh, 2003). It postulates a generalized and innate frontoparietal cortical mechanism for mapping non-symbolic quantities across domains and modalities: "bigger, faster, brighter, further in one domain should correlate with bigger, faster, brighter, further in another" (Walsh, 2015, p. 557). These experiential correlations for non-symbolic quantities are the mechanism by which a Theory of Magnitude can explain the grounding of numbers, as well as various non-spatial motoric congruency effects. For example, larger numbers facilitate stronger responses while smaller numbers are congruent with weaker responses (Krause et al., 2014; Vierck & Kiesel, 2010). Moreover, larger symbolic numbers facilitate power grip responses and smaller numbers facilitate precision grip responses (Andres et al., 2004, 2008; Lindemann et al., 2007; Namdar et al., 2014). These observations beautifully illustrate how sensory and motor activity is systematically associated with magnitude representations in our bodies. Clearly, it will be of interest to investigate the timing of such motor signatures for numerical embodiment of numbers, in an attempt to place constraints on cognitive models of such associative knowledge retrieval. We will describe one recent attempt at this below.

Finger Counting Hypothesis

Finally, even in adults, number processing is still shaped by childhood finger counting habits (Di Luca et al., 2006; Domahs et al., 2010; Fischer, 2008; Sixtus et al., 2017, 2018). This third proposal for the

embodied nature of numbers is the most specific with regard to the mechanism of number meaning construction. We can distinguish two basic patterns of finger counting, namely counting from the left hand (left-starters; left thumb is "one", left index is "two", etc.) or from the right hand (right-starters). Such patterns are idiosyncratic but also exhibit cross-cultural as well as intra-individual (often called "situated") variability (Lindemann et al., 2011; Lucidi & Thevenot, 2014; Wasner et al., 2014). Finger counting is a nearly universal mechanism for learning numbers and thus a prime example of embodied knowledge (Fischer & Brugger, 2011). Unlike SNARC, the finger counting effect should be associated with the person's hands rather than with their peri-personal space (Di Luca et al., 2006; Tschentscher et al., 2012). Thus, the third proposal about embodiment of number knowledge struggles to explain why, with crossed hands, we are still faster to classify small numbers with left-side buttons even when using the right hand to do so (Dehaene et al., 1993, Experiment 6). Unlike a Theory of Magnitude, the finger counting proposal focuses on discrete quantities and struggles to explain how continuous magnitudes relate to the body.

Each of these three accounts for the embodied representation of number concepts as a result of sensory and motor experiences has gathered experimental evidence. For example, Wiemers et al. (2017) analyzed congruency effects in response to small versus large numbers that were successively presented in either a small or large font. Their participants activated both MNL representations (processing of number magnitudes) and Theory of Magnitude-based representations (processing of number sizes). Conversely, Krause et al. (2014) instructed participants to make more or less forceful responses to small and large numbers and found that different participants showed either Theory of Magnitude- or MNL-based patterns. When participants simply classified numbers from 1 to 10 with their ten fingers to press corresponding buttons, Di Luca et al. (2006) found that finger counting explains the results better than the MNL account. Finally, Fischer (2008) found a modulation of the SNARC effect by finger counting habits, confirming the coexistence of both MNL and finger counting in representations of number knowledge. These and other debates about the embodied nature of number meaning set the

stage for our report of recent research from the Potsdam Embodied Cognition Group.

Getting a Grip on Numbers

One important constraint for models of cognition is the time course of knowledge activation. For example, it is considered a hallmark of embodiment that the motor cortex becomes active in under 170 ms when we read action verbs, thereby making a constitutive contribution to comprehension and eliminating the possibility that this activation occurs as an epiphenomenal after-effect (Hauk et al., 2004; Pulvermüller, 2005). Using highly time-resolved methods to measure motor resonance during meaning-making is therefore an important endeavor. Moreover, the conflicting previous work on embodied numerical cognition can be criticized by pointing out that most studies of MNL, a Theory of Magnitude, and finger counting relied on explicit instructions that may not represent "normal" number processing. These two concerns can be addressed by using a relatively new technique—spontaneous grip force recording (Aravena et al., 2012, 2014). This technique allows researchers to identify the timing of semantic effects with millisecond precision and without the need to even perform any motor response.

In the Potsdam Embodied Cognition Group, we recently showed long series of single digits to adult participants (habitual left-starters and right-starters, respectively) while they held in each hand a small grip force sensor (see Fig. 7.1, Panel A; for methodological details, see Miklashevsky et al., 2020; Nazir et al., 2017). Participants viewed all numbers passively unless (occasionally) a number was repeated, in which case they had to say that number aloud. Analyzing only no-go trials and using vocal responding in go trials excluded any confounds related to motor responses and ensured that all effects were instead related to the processing of number meaning itself. Importantly, all numbers were presented pseudo-randomly in mini-blocks, where small numbers (1–4) were grouped together, as were large numbers (6–9). For example, a participant would see the following digit sequence: (3 4 1 2) (8 6 9 7) (1 4 3 2) … etc. Note that brackets are inserted here only to clarify the rationale. Using our 1-back working

memory task, we ensured that the presented number and the number currently held in working memory were of similar magnitudes in most cases; this was intended to bring out the relation between number meaning and spontaneous grip force change that was studied here.

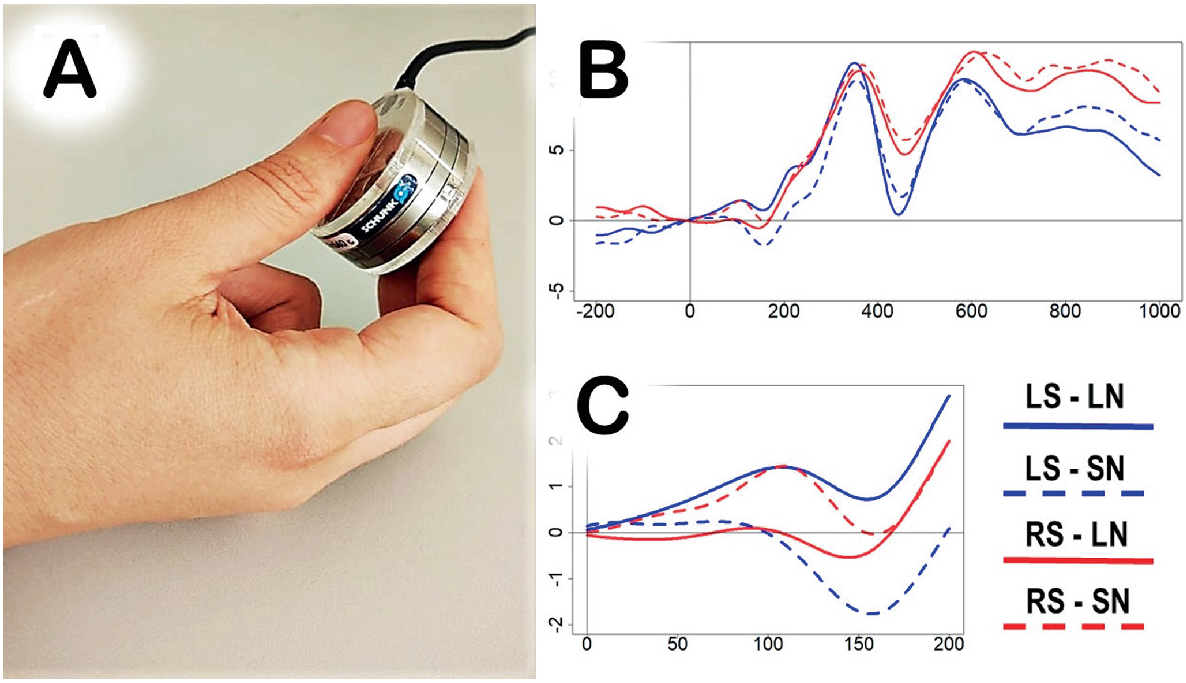


Fig. 7.1 ***Panel A***. Grip force sensor as held during data acquisition. ***Panel B***. Averaged and stimulus-locked left-hand change of grip force (in milli-Newton along the y-axis), plotted separately for left- and right-starters (LS and RS, respectively) while processing small versus large numbers (SN vs. LN, respectively). X-axis represents time in ms. ***Panel C.*** Magnified time window from 0 ms (stimulus onset) to 200 ms. See text for more details

Data were analyzed similarly to electro-encephalography data, including averaging across many trial repetitions, normalizing relative to an individual's baseline grip force, and aligning each curve to the onset of the stimulus. Our first interesting observation was that, across all trials, a systematic pattern appeared, with a first wave of motor activity already at 75–100 ms after number onset, followed by a second wave reaching its peak at 350 ms, and a third wave peaking at around 600 ms. In analogy to the interpretation of similar multi-phasic electro-encephalography patterns (see Hsu & Szűcs, 2012), we believe that these waves reflect three different cognitive processes: initial stimulus coding, decision-making (i.e., whether there is a number repetition or

not), and replacing the number in working memory to prepare for the next trial, as our 1-back task requires.

Already 100–140 ms after number onset (initial stimulus coding) we found a signiﬁcant triple interaction between ﬁnger counting preference, number magnitude, and hand: left-starters spontaneously press their left sensor stronger when seeing large numbers (i.e., from 6 to 9), whereas right-starters spontaneously increase their left grip force for small numbers (i.e., from 1 to 4). At ﬁrst glance, this early effect seems confusing because it apparently conﬂicts with ﬁnger counting habits, but there was another time window (570–600 ms, reﬂecting working memory updating) where a grip force pattern compatible with participants' ﬁnger counting was observed: left-starters had signiﬁcantly lower grip force in their right hand for large numbers, with the opposite tendency in right-starters.

In our interpretation of the data, we follow the logic of the HANDLE model (García & Ibáñez, 2016), which was recently developed to describe interactions between language understanding and the motor system. We suggest that hand-related neural networks in the brain, which are differentially associated with large versus small numbers, activate during number storage in working memory (570–600 ms in our paradigm). This might, in turn, lead to inhibition already at 100–140 ms when the subsequent number with similar magnitude is presented. Our preliminary results (Fig. 7.1, Panels B and C) show that ﬁnger-counting habits and cortical magnitude processing interact extremely quickly to determine a meaningful response to number symbols, supporting the embodied nature of number meaning.

Embodying Negative Numbers

From an embodied perspective the challenge from abstract concepts is perhaps even more difficult with negative numbers. They, unlike positive numbers, cannot ever refer to real-world objects or sets. Using chronometric methods and established tasks such as speeded magnitude comparison ("Which of two numbers is numerically larger?"), we showed previously that negative numbers are processed slower than positive numbers (e.g., Fischer, 2003; Fischer & Rottmann, 2005). This is not surprising because negative number concepts are

learned later in life (e.g., Blair et al., 2012; Siegler, 2016). However, negative and positive numbers also exhibit several processing similarities (Mende et al., 2018), and these similarities were the motivation for us to ask whether negative number concepts may also be represented as embodied knowledge.

So what are these cognitive similarities? First, positive digit pairs are processed faster when their numerical values are farther apart, so that it is easier to classify 2 as smaller than 5 compared to 4 versus 5 (the ***distance effect***; see the classic study by Moyer & Landauer, 1967). In negative numbers, a similar distance effect was reported (e.g., Ganor-Stern, 2012, but see Fischer & Rottmann, 2005, or Varma & Schwartz, 2011, for contradicting results). Finding the distance effect is a fundamental piece of evidence against viewing the human mind as a computer because it shows that the semantic similarity between distinct symbols affects cognitive performance. This can be interpreted as showing that some sensory or motor aspect of the referents of these symbols is preserved in such analog representations. Second, the ***SNARC effect*** (see above) seems to extrapolate from positive to negative numbers, placing them to the left of zero on a leftward-extended MNL (Fischer, 2003). Of course, the MNL is merely a conceptual metaphor, a hypothetical cognitive mechanism that applies experience-based reasoning to the realm of abstract concepts. Alternatively, we may adopt a rule that relates positive and negative number concepts: By ignoring the minus sign we can then understand corresponding positive numbers in an inverted manner—i.e., by increasing the absolute value when subtracting and decreasing it when adding.

Both the extended MNL and the rule-based approach to representing negative numbers have received support in experimental research with spatially distributed stimuli and/or responses. These task-speci□ic spatial features are, however, are also a possible source of con□licting □indings and methodological concern (cf. the review by Mende et al., 2018). In an attempt to reduce contamination of performance from such extraneous factors, Fischer and Shaki (2016, 2017; see also Shaki & Fischer, 2018) developed a new method for assessing spatial-numerical associations without spatial features in either the stimulus or the response, thus isolating the purely

conceptual content of numbers. This is a pre-requisite for answering the question whether number meaning is inherently spatial in nature. What would happen when we apply this new method to negative numbers?

In one recent study with negative numbers (Mende et al., 2020), participants tested by the Potsdam Embodied Cognition Group saw long random sequences of numbers and arrows appear at their central fixation point on a screen. They performed a go/nogo task on a single button by responding to conjunction rules such as "press the button if the number magnitude is smaller than −5 OR for left-pointing arrows" that were announced prior to each sequence. We compared number processing under four mental sets that resulted from combining the rule components "smaller than −5" and "larger than −5" with "left-pointing" and "right-pointing". The first important observation was that in all conditions negative numbers show a pronounced distance effect relative to the reference value −5; this confirms the processing of magnitude meaning. Furthermore, performance (depicted in Fig. 7.2 below) showed that "smaller/left" and "larger/right" were easier (and thus cognitively compatible) mental sets: semantically smaller negative numbers (from −6 to −9) are thus associated with left-most space (Mende et al., 2020). This result is in line with the extended MNL account and shows that embodiment signatures can extend to negative number processing.

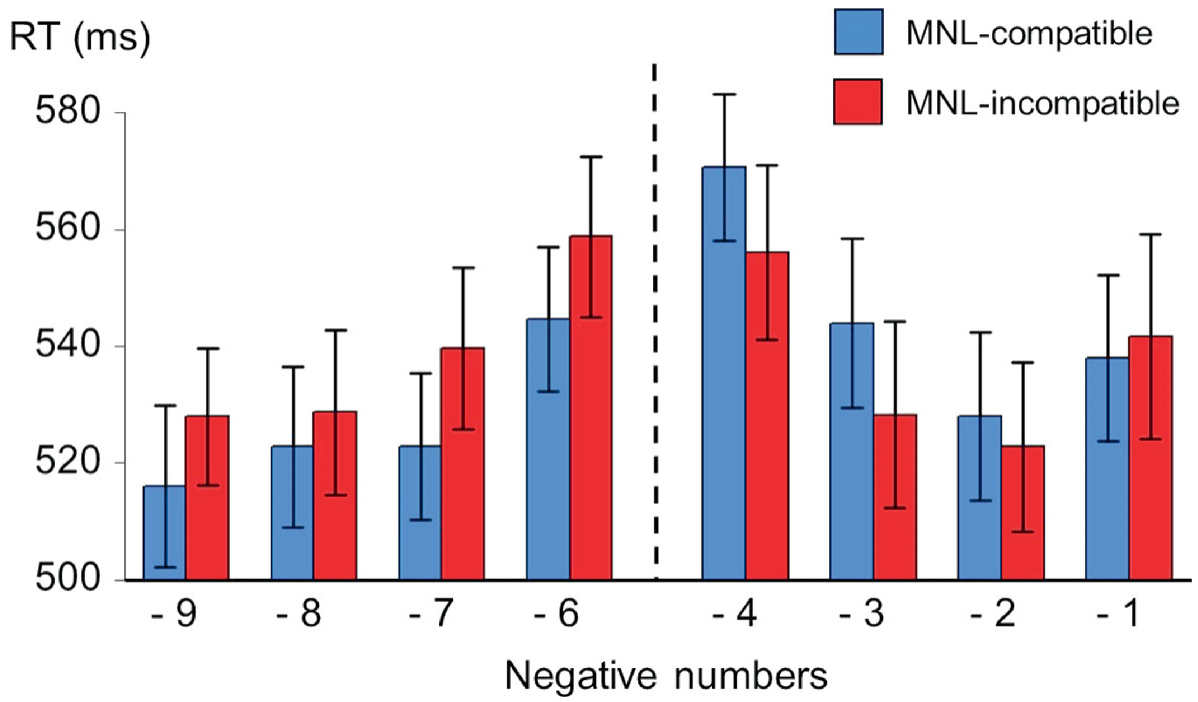


Fig. 7.2 Mean reaction times (RTs) when classifying negative numbers relative to minus 5 (vertical dashed line). Participants worked in four separate blocks under conjunction rules that were either compatible (blue) or incompatible (red) with an extended mental number line. Compatible rules: respond to numbers from −6 to −9 and left-pointing arrows; or to numbers from −1 to −4 and right-pointing arrows. Incompatible rules: respond to numbers from −6 to −9 and right-pointing arrows; or to numbers from −1 to −4 and left-pointing arrows. Error bars show 1 standard error of the mean

Interestingly, however, responses to semantically larger negative numbers (from −1 to −4) were classified faster in ***incompatible*** conditions—i.e., these numbers were associated with left space, similarly to their positive counterparts, as can be seen in Fig. 7.2. This result supports the rule-based account: Participants activated positive number representations and then simply reversed the result. It should be noted that in this experiment some positive numbers from 6 to 9 had been interspersed to prevent participants from ignoring the minus sign and relying on rule-based strategies alone. Thus, we demonstrate here the flexible or situated nature of negative number representations: depending on the experimental context, some of the numbers are represented spatially on the extended MNL, while others are derived from positive numbers based on inversion rules, even within the same experiment.

Given that negative numbers have spatial associations and show distance effects, we conclude that their cognitive representation is similar to that of positive numbers, despite their seemingly more abstract nature. Among the three embodied accounts for number knowledge under consideration, only the MNL metaphor appears to be consistent with the evidence by postulating a leftward extension of the MNL beyond zero. A Theory of Magnitude does not currently offer a mechanism for experiencing negative magnitudes. Similarly, habitually counting down below zero on one's fingers has, to our knowledge, not been documented. It is, however, feasible and may occur when children begin to extend their number knowledge beyond the natural numbers in the context of mental arithmetic, a topic to which we now turn.

Embodied Heuristics and Biases in Mental Arithmetic

Mental arithmetic has long been considered as example par excellence for the abstract nature of human cognition as symbol manipulation, applying operations not principally different from those of a computer (Friedenberg & Silverman, 2006). Yet, even here the embodied approach to cognition has made significant inroads toward a more appropriate understanding, according to which simple arithmetic operations are shaped by our sensory and motor experiences of manipulating quantities in space (e.g., Lakoff and Núñez, 2000). For example, we are better at addition while making right-ward movements and better at subtraction while making left-ward movements (Werner et al., 2018; Wiemers et al., 2014). Under conditions of time pressure and uncertainty about the quantities to be considered, we take cognitive shortcuts that lead to systematic performance biases. This "heuristics and biases" approach to cognition was established by Tversky and Kahneman (1974; see Kahneman et al., 1982) and can also be found in other realms of reasoning. A famous example for a numerical reasoning bias is ***anchoring***: it refers to the influence that the first number we encounter has on our subsequent quantitative estimates (Tversky & Kahneman, 1974). Systematic biases in reasoning can reveal fundamental constraints on cognition (e.g., Gigerenzer & Gaissmaier, 2011).

In mental arithmetic, there are several heuristics and biases at work which can be tied to grounded, embodied, and situated representations and processes, as described above. For example, we tend to underestimate the results of subtraction problems and to overestimate the results of addition problems, in close analogy to making movements along the MNL that go too far to the left when subtracting and too far to the right for adding. This ***Operational Momentum effect*** was first discovered when adult participants evaluated changes in amounts of visually presented dot clouds (McCrink et al., 2007). More recently, the presence of Operational Momentum in nine-month-old infants led McCrink and Wynn (2009) to postulate an early-acquired heuristic "if adding, accept more; if subtracting, accept less", consistent with everyday embodied experiences from manipulating quantities. Operational Momentum emerged not only in numerosity estimation but also in numerosity production, when using hand rotations to increase or decrease the amount of dots on a screen (Lindemann & Tira, 2015), or when pointing to arithmetic results on a visually presented number line (Pinhas & Fischer, 2008). Thus, physical activities or the underlying motor simulations of such activities might be at play when we produce Operational Momentum.

Several theoretical accounts for Operational Momentum have been proposed (reviewed in Fischer & Shaki, 2014) but they struggle to accommodate two peculiar observations: First, there is ***larger*** Operational Momentum when the second operand is zero (so-called zero problems, e.g., 4 + 0; 4 − 0), in contradiction with the idea that the second operand determines the size of the movement along the MNL (cf. Pinhas & Fischer, 2008). And second, in some studies there is ***reverse*** Operational Momentum (associating subtractions with larger outcomes than additions) when the second operand is different from zero (so-called non-zero problems, e.g., 3 + 1; 5 − 1); presumably, this reflects anchoring because for equal outcomes the first operand must be larger in subtractions than in additions.

A viable account of these and other phenomena related to mental arithmetic from an embodied perspective is offered by the "***Arithmetic Heuristics and Biases***" model (Shaki et al., 2018; Felisatti et al., 2020a, b). It postulates the presence of multiple, competing non-spatial and

spatial heuristics and biases that together produce the observable Operational Momentum (see Table 7.1): ***The more-or-less heuristic***, reflecting physical laws that we experience from birth when we manipulate magnitudes; an ***anchoring effect*** according to which the first magnitude we encounter affects subsequent magnitude processing; an ***operation sign-space association*** which reflects our experiences in symbol manipulation whenever the arithmetic task has a spatial ingredient, namely that bigger numbers are on the right; and an ***operand order compatibility effect*** between the MNL and the order of operands in the current problem; smaller first operands are congruent with the MNL.

Table 7.1 Cognitive mechanisms in the arithmetic heuristics and biases model of Shaki et al. (2018) and Felisatti et al. (2020a, b) to explain operational momentum effects. See main text for details

Cognitive mechanism	Definition	Knowledge level	Task domain	Sample references
More or less heuristic	Additions-more subtractions-less	Grounded	All problems	McCrink and Wynn (2009)
Anchoring effect	Magnitude of the 1st operand	Situated	Non-zero problems	Tversky and Kahneman (1974); Shaki et al. (2018)
Operation sign-space association	Plus-right minus-left	Embodied	Spatial tasks	Pinhas et al. (2014), Hartmann et al. (2015), Masson and Pesenti (2016)
Operand order compatibility effect	Congruity between operand order and MNL	Situated	Spatial tasks; additions	Shaki et al. (2015), Zhou et al. (2012), Felisatti et al. (2020a, b)

The four mechanism proposed by the Arithmetic Heuristics and Biases model were recently evaluated by the Potsdam Embodied Cognition Group with an experiment where adults expressed results of arithmetic problems as lengths of an unbounded visual line (as in Cohen & Blanc-Goldhammer, 2011). Our study compared performance in three tasks with different degrees of spatial involvement: The ***Shifting the Marker*** and ***Shifting the Line*** tasks required dragging either a marker or the line itself according to the result, thus generating mental movements along the MNL that were either congruent or incongruent with the physical movements and, consequently, boosting or reducing the operation sign-space association. The ***Line Length***

Production task (Shaki et al., 2015), instead, removed spatial features (and thus operation sign-space association) by using a single response button and bi-directionally changing line lengths. The methods and preliminary result of the study are depicted in Fig. 7.3. We discuss them briefly to illustrate the workings of the Arithmetic Heuristics and Biases model.

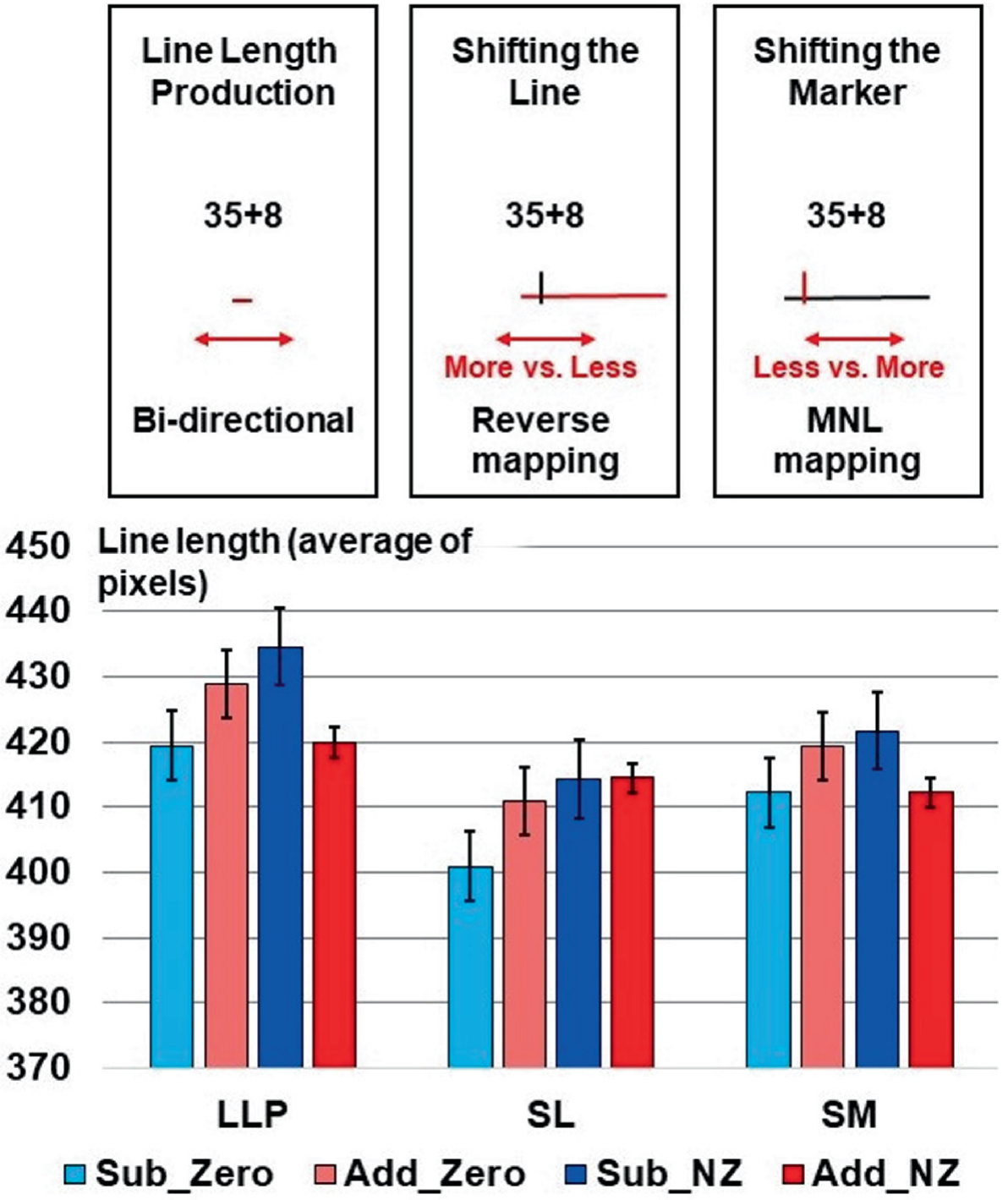


Fig. 7.3 Line lengths in three tasks with different combinations of the cognitive mechanisms postulated by the Arithmetic Heuristics and Biases model of mental arithmetic. Operational Momentum is computed as the difference between addition (Add) and subtraction (Sub) performances for identical arithmetic results (e.g., 35 + 8 and 51 − 8, respectively). Importantly, Operational Momentum differs for problems with either zero (Zero) or non-zero (NZ) as second operand. For more details, see main text. Error bars are 1 standard error of the mean

Our preliminary results corroborate previous findings (Shaki et al., 2018): when the second operand of an arithmetic problem equaled zero (e.g., 43 + 0, 43 − 0), longer/shorter line lengths were accepted after additions/subtractions, respectively (regular Operational Momentum). Conversely, when the second operand of an arithmetic problem differed from zero (e.g., 35 + 8, 51 − 8), the opposite pattern was found with tendency to accept shorter/longer line lengths after additions/subtraction, respectively (reverse Operational Momentum). According to the Arithmetic Heuristics and Biases model, the crucial difference between zero-problems and non-zero problems consists of presence or absence of anchoring effect: Indeed, in zero-problems the more or less heuristic and the operation sign-space association are not influenced by the anchoring effect since both operations begin with the same first operand. A second interesting finding concerns the role played by the task: While in zero problems, the regular Operational Momentum was comparable across tasks; in non-zero problems the reverse Operational Momentum was influenced by task. Shifting the Line cancelled the differences between additions and subtractions in non-zero problems, resulting in comparable line length across operations. Also this modulation is well explained in light of the Arithmetic Heuristics and Biases model: While in Shifting the Marker, the consistency of the operation sign-space association component with the MNL direction strengthens the anchoring effect by attracting the solution toward the anchor (i.e., the first operand), in Shifting the Line, the inconsistency of operation sign-space association with the MNL dilutes the anchoring effect by stretching the solution away from the anchor. Finally, the irrelevance of operation sign-space association in the non-spatial Line Length Production task demonstrates the pervasive role of anchoring even without spatial confounds.

Focusing on addition problems, we also found that operand order played a significant role: When it was consistent with the MNL direction (first operand smaller than second operand, e.g., 8 + 35), stronger overestimation (longer line lengths) was observed rather than when it was inconsistent (first operand larger than second operand, e.g., 35 + 8). This occurred in ***Line Length Production*** and ***Shifting the Marker***, while the opposite pattern emerged in ***Shifting the Line***, with stronger overestimation when operand order was

inconsistent with the MNL direction rather than when it was consistent. The results are informative about the reciprocal influence of the Arithmetic Heuristics and Biases model's components: When operation sign-space association is irrelevant (in ***Line Length Production***) or congruent (in ***Shifting the Marker***) with the MNL, then operand order compatibility bias follows the MNL-mapping, resulting in overestimation when the larger operand is on the right of the operator (e.g., 8 + 35); conversely, when operation sign-space association is inconsistent with the MNL (in ***Shifting the Line***), then operand order compatibility bias follows the reverse MNL-mapping, resulting in overestimation when the larger operand is on the left of the operator (e.g., 35 + 8; Felisatti et al., 2020a, b). Together, these results illustrate that, like all seemingly rational thought, arithmetic reasoning is prone to heuristics and biases that reflect grounded, embodied, and situated knowledge constraints on cognition.

We have extended the reach of embodied theorizing about human numerical cognition from positive to negative numbers and even to mental calculation. In this endeavor, it has become clear that spatial behaviors and spatial cognitive representations together provide a lever for understanding the nature of conceptual knowledge. Specifically, we have induced and measured spatial congruency effects in order to draw inferences about the mental representation of numbers, which is shaped by spatial experiences. We have also removed spatial features from the stimuli and responses in order to examine the purely conceptual level of number representation. In the last section of this chapter we extend this methodological approach to show that other domains of spatially mediated cognition can, in turn, influence the domain of number processing.

Connecting Mathematics with Emotions

Refuting the traditional view of cognition as "cold" computation, emotions influence various cognitive processes, such as conceptual processing, reasoning, attention, memory, and decision-making (Bartolic et al., 1999; Guo et al., 2018; Hayakawa et al., 2017; Lench et al., 2011; Morgan & D'Mello, 2016; Peper et al., 2017).

However, only a few studies so far attempted exploring the effects of emotional processing on arithmetic problem-solving and have yielded inconsistent results: Schimmack and Derryberry (2005) found that positive or negative pictures slowed down multiplication when compared to neutral pictures. In contrast, Fabre and Lemaire (2020) recently showed that negative pictures facilitated multiplication verification, due to faster disengagement from the picture compared to positive pictures, which in turn slowed participants down. In these studies, findings were interpreted in terms of general effects of emotions (Morgan & D'Mello, 2016) without considering the ***embodied*** mechanisms that may also contribute to these effects and potentially explain some of the variability.

The Potsdam Embodied Cognition Group, in contrast, focuses on embodied aspects of both emotions and arithmetic and suggests that they may constitute a common ground for cross-domain links (Myachykov et al., 2016). More specifically, when embodied agents interact with their environment in different contexts, consistent multimodal spatial associations are being formed. Just like mental calculations (see above), emotional states are also mapped onto mental space, which is reflected in universal metaphors (e.g., happy is up, sad is down). Such associations, in turn, induce systematic spatial congruency effects. We describe a few example studies to document this novel insight before describing our test of the link between arithmetic and emotional experiences at the level of overlapping embodied representations.

Participants in the study by Holmes and Lourenco (2011) performed a "Numbers and Faces" task that required parity and gender judgments on left- and right-side response keys. Participants were able to "automatically extract magnitude relations from (emotional) faces, mentally organizing this information in a spatial format" (p. 318). Therefore, the left-to-right orientation extended from the number domain to the domain of emotions. By testing positive versus negative faces in the same paradigm, the authors also found faster right responses for ***more emotional*** stimuli, regardless of their valence. Further, Fantoni et al. (2019) recently found that faster choices between emotionally charged faces is mediated by an increase in emotion intensity of the relevant facial expressions.

Pitt and Casasanto (2018) asked their participants to classify emotional adjectives in terms of (1) positive/negative valence and (2) magnitude (more/less intensity of emotion). They found systematic ***valence***-based spatial associations of ***negative*** words with left-hand responses and ***positive*** words with right-hand responses in right-handed participants, but no systematic lateral mapping based on emotion ***magnitude***. Therefore, Pitt and Casasanto (2018) suggested that positive emotions are implicitly associated with the more dexterous side of space and negative emotions with the non-dexterous side (Casasanto, 2009, 2011, 2014). However, more recent results of Holmes et al. (2019) with word stimuli revealed an association of less emotion with left space and more emotion with right space, which gave support to spatial mapping of emotion ***magnitude***. Therefore, it is currently unclear which dimension of emotions—their valence or magnitude—guides their horizontal spatial associations. We examined the magnitude and valence hypotheses by combining emotional and arithmetic processing.

The Potsdam Embodied Cognition Group set out to explore cross-domain priming between emotion and arithmetic by utilizing their common spatial representations (Kulkova & Fischer, 2020). Participants verified two types of multi-digit arithmetic addition and subtraction facts: easy "non-carries" (e.g., 25 + 33 = 58) and difficult "carries" (e.g., 43 − 16 = 27) where the calculation crossed a decade boundary and presumably required one to carry a decade value in memory. Arithmetic problems were preceded by task-irrelevant pictures containing one of three emotions: positive, neutral, or negative (see Fig. 7.4, Panel A), depicting either human faces or equally emotional landscapes, animals, and objects for 1000 ms. Responses were recorded per voice key to avoid spatial coding of manual choice responses.

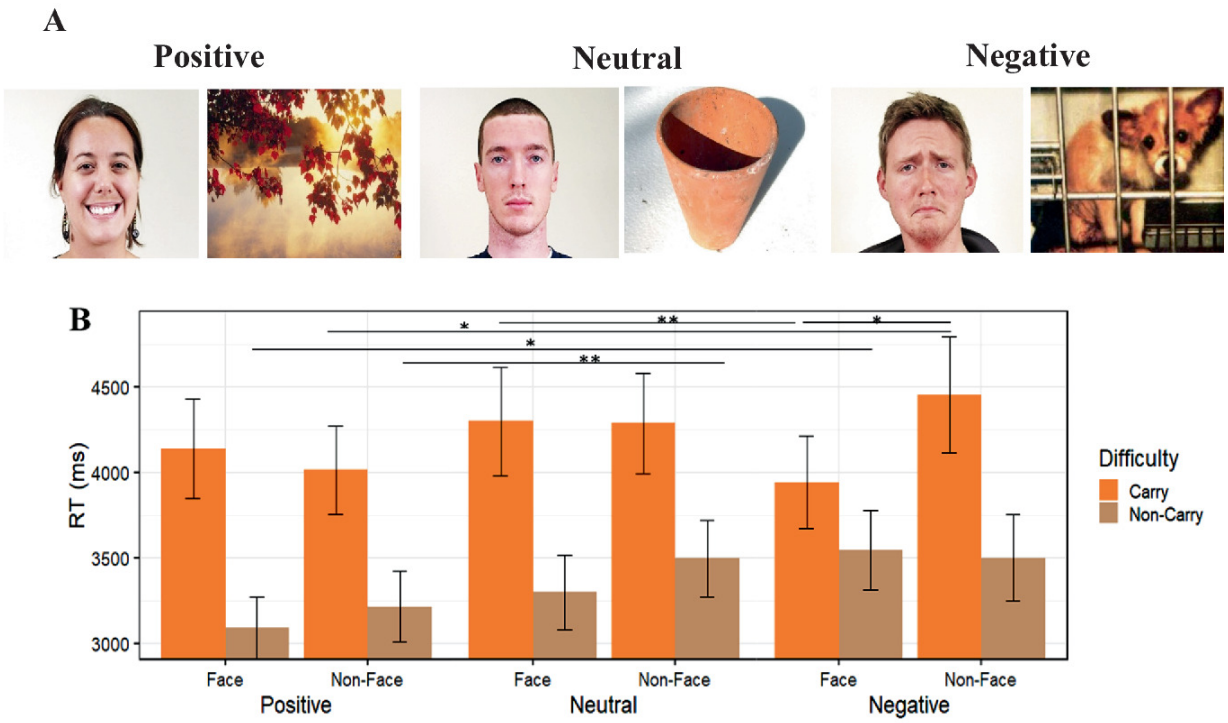


Fig. 7.4 Methods and results for cross-domain emotional priming of arithmetic verification. ***Panel A***. Examples of priming images. ***Panel B.*** Main results for addition, *$p < 0.005$, **$p < 0.05$. Vertical bars represent 1 standard error of the mean

Following all three emotions, addition problems were processed faster than subtraction problems, consistent with typical results for mental arithmetic (Campbell, 2008; De Smedt et al., 2009). More interestingly, addition problems primed by positive images were processed faster than the same problems primed by neutral images. This novel result supported our main hypothesis, which was in agreement with both the magnitude and valence accounts.

To clarify this issue, we conducted a follow-up analysis for addition and subtraction problems separately. Considering addition problems, we found RT facilitation for positive compared to negative pictures for easy problems that were primed by facial expression pictures; we found the same for difficult problems primed by non-facial images. Moreover, easy additions primed by non-face images were judged faster when the images were positive, but not neutral, in valence. At the same time, difficult addition problems, primed by negative facial expression pictures, were processed faster compared to the same problems primed by neutral facial expression pictures and negative non-facial pictures. Panel B of Fig. 7.4 shows these results.

To sum up, processing addition problems was facilitated when primed by positive compared with negative images and by both positive and negative emotional images compared with neutral images. These results suggest that (1) there are cross-domain correspondences between emotions and arithmetic, driven by their embodied spatial associations and (2) arithmetic problem-solving is facilitated when the activated associations are congruent. Additionally, difficult additions were processed faster after negative images denoting faces, compared to negative images of emotional landscapes, animals, or objects. This suggests a facilitatory role of emotional facial expressions that may have evolutionary and social foundations. The fact that we found significant emotional priming effects for addition, but not for subtraction problems, is in line with a report by Montefinese et al. (2017), who found that complex mental additions had stronger spatial associations than complex subtractions. However, our findings do not provide conclusive evidence in support of either the valence or magnitude account of emotional spatial mapping: the patterns we found were more complicated and probably also driven by such factors as problem difficulty and differences in processing various types of priming images. Therefore, more work is needed to establish how emotional states and traits of the body interact with valence and magnitude processing in the mind.

Conclusions

The present review of recent studies from our lab illustrated the benefits of the conceptual clarification that results from distinguishing grounded from embodied and situated cognition. These benefits were illustrated with several attempts to push the envelope of embodied theories of the mind into the realm of numerical cognition, a domain of knowledge representation that was traditionally thought of as a hallmark of the mind as a computer. The four sections on grip force fluctuations during single-digit processing, comprehension of negative numbers, embodied mental arithmetic, and the link between arithmetic and emotions had in common the theme of searching for performance signatures that are inconsistent with such a traditional understanding of cognition as abstract symbol manipulation.

Recording spontaneous changes in grip force during number comprehension with high temporal resolution places important constraints on cognitive theories by specifying the moment at which bodily signals can first contribute to meaning-making. It also underlines the importance of acknowledging individual differences in sensory and motor experiences, which is a key strength of an embodied account of human cognition. Examining whether signatures of analog number representation extend from positive numbers to negative numbers helps us to develop recommendations for educational practice but also requires us to reflect upon the interpretational limits of mental chronometry. The analysis of component processes of mental arithmetic from an embodied perspective reveals novel heuristics and biases that contribute to our everyday quantitative reasoning and call for better specification of their relative weights. And the study of cognitive mechanisms at the interface between distinct cognitive domains such as emotional and arithmetic processing has the potential to uncover broad principles of the human mind if the results replicate across cultures and methodologies. Overall, we believe that these different projects provided evidence that converges on the idea that our minds control our bodies so effectively because these bodies have shaped our minds through their grounding, embodiment, and situatedness.

Acknowledgements

Preparation of this chapter was partially funded by grant DFG-FI-1915/8-1 “Competing heuristics and biases in mental arithmetic” from Deutsche Forschungsgemeinschaft to MHF. We thank the editors for valuable comments on an earlier draft.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_8

8. The Challenges of Abstract Concepts

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Abstract
Some have recently suggested that abstract concepts do not constitute a substantial challenge to embodied cognition because they do not form a unified category. In this chapter, I argue that abstract concepts are indeed heterogeneous but as such pose several distinct theoretical challenges. After surveying the current evidence for, and responses to, these challenges, I conclude that a comprehensive embodied account that addresses the diversity of abstract concepts remains possible. Several desiderata for a future theory emerge from this critical review. A successful theory will need to embrace not only distributed multimodal representations but also recognize the importance of the emotions and the language system; to posit a hierarchical architecture that includes cross-modal convergence zones or hubs; and to provide a robust explanation for the semantic flexibility of concepts in general and abstract concepts in particular.

Keywords Abstract concepts – Embodied cognition – Theory – Mind

The growing interest in embodied psychology is due in part to the existence of a robust body of evidence suggesting that thinking is often grounded in experiential systems (Borghesani & Piazza, 2017; Fischer

& Zwaan, 2008; Kemmerer, 2010). This evidence provides good reason to believe that human thought is not independent from action, emotion, and perception, but is instead dependent on the selective reuse of experiential systems (Barsalou, 1999, 2008; Fischer & Zwaan, 2008; Gallese & Lakoff, 2005; Glenberg & Gallese, 2012; Pulvermüller, 2005). For the most part, researchers exploring the embodied nature of thought have focused on concrete concepts (Chatterjee, 2010; Mahon & Caramazza, 2008; Pulvermüller, 2005). Recently, though, there has been a rapid growth of interest in abstract concepts, and this has led to a number of studies that implicate experiential systems in the representation of abstract concepts (e.g., Dreyer et al., 2015; Glenberg et al., 2008; Lynott & Connell, 2013; Mason & Just, 2016; Moseley et al., 2012).

Part of the reason for this burgeoning research program is that abstract concepts threaten embodied cognition in several ways (Dove, 2016; Myachykov & Fischer, 2019). First, many abstract concepts refer to objects and events that we do not directly experience (Borghi & Binkofski, 2014; Borghi et al., 2017). Given this, it is not immediately clear how they can be grounded in action, emotion, and perception systems (Mahon, 2015; Mahon & Caramazza, 2008). Second, a diverse body of behavioral and neuropsychological research suggests that abstract and concrete concepts are at least partially handled by distinct neuroanatomical structures (Binder et al., 2009; Wang et al., 2010). Third, there is a question of the scope of conceptual grounding; it is simply not clear that all concepts are grounded all the time (Pecher, 2018; Pexman, 2017).

Abstract concepts can range over a number of different areas of human activity and interest. This can be seen in the contributions to a recent special issue focused on the varieties of abstract concepts (Borghi et al., 2018). Some abstract concepts involve lofty moral and aesthetic notions such as ***beauty***, ***freedom***, ***justice***, ***piety***, and ***sin*** (Fingerhut & Prinz, 2018). Others involve emotions such as ***desolation***, ***gratitude***, ***pleasure***, ***resentment,*** and ***schadenfreude*** (Winkielman et al., 2018). Many appear dependent on social and cultural factors such as ***celebrity, demagogue, martyr***, ***scapegoat***, and ***xenophobe*** (Rice et al., 2018). Yet another group consists of mathematical and scientific concepts such as ***force, infinity, odd number, pi***, ***quark***, and ***zero*** (Desai et

al., 2018). Some are associated with language use such as ***assert***, ***cajole***, ***lie***, and ***promise*** (Dove, 2018). Although often overlooked, natural languages rely on grammatical elements associated with abstract concepts such as articles (***a*** and ***the***), modal verbs (***can***, ***may***, ***must***, ***shall***, and ***will***), negatives (***not***), and quantifiers (***few***, ***most***, ***some***, and ***all***) and can vary in terms of which specific lexical elements are grammaticalized (Kemmerer, 2019).

Borghi and Binkofski (2014) characterize abstract concepts as concepts that refer to events, mental states, and situations rather than concrete, manipulable objects or entities; involve complex properties and relations; and are more variable than concrete concepts with respect to semantic content. While this characterization might succeed with respect to breadth and inclusiveness, it also depends on the conjunction of several potentially orthogonal features. The purpose of this chapter is to critically assess the nature and force of the challenges posed by abstract concepts to embodied cognition. I argue that, as a heterogeneous class, they raise a number of distinct research questions that may ultimately require distinct theoretical explanations (Desai et al., 2018).

Concreteness Effects

A longstanding body of evidence suggests that abstract concepts are processed differently than other concepts. This evidence often relies on a two-step process. First, some measure of relative abstractness is developed, formulated, and tested for reliability. Next, researchers gather behavioral or neurocognitive results by means of experimental paradigms that incorporate stimuli that have been rated by means of that measure.

Concreteness effects are the most established and widespread example of this sort of research. ***Concreteness*** is typically defined as the extent to which an item or event can be experienced by the senses (Paivio, 1971). Another long-used measure is that of ***imageability***. Imageability is typically defined as the subjective ease with which a word gives rise to sensorimotor mental imagery (Bird et al., 2001; Paivio, 1986). It is far from clear which of these two measures best captures the relevant phenomenon of abstractness. Although they

correlate to a fairly high degree and are often used interchangeably, they are not equivalent. Signi cantly, concreteness ratings have a bimodal distribution while imageability ratings have a unimodal distribution (Richardson, 1975). Vigliocco et al. (2011) suggest that concreteness ts better with the ontological distinction between abstract and concrete entities, but others argue that imageability is preferable because it ts better with the overall clinical, developmental, and experimental data (Bird et al., 2003; Paivio, 2013). We also need to acknowledge the possibility that the two measures could ultimately track different aspects of a single underlying distinction.

Concrete (or highly imageable) words have been shown to enjoy a number of processing advantages over abstract ones. Experiments with neurotypical participants nd that abstract words are processed less ef ciently than concrete words in tasks that involve word recognition (Evans et al., 2012), repetition (Tyler et al., 2000), recall (Jefferies et al., 2006; Paivio, 1986; Romani et al., 2008), and comprehension (Kounios & Holcomb, 1994; Schwanen ugel & Shoben, 1983). In addition, people tend to produce better de nitions for concrete concepts than they do for abstract ones (Goetz et al., 2007).

More recently, a motor-related measure has been used to similar effect. The dimension of ***body–object interaction*** (BOI) is meant to capture the ease with which a human body can physically interact with category exemplars. A number of studies have indicated that words with higher BOI ratings are processed more ef ciently than words with lower BOI ratings (Wellsby et al., 2011; Yap et al., 2012).

Inspired by the evidence for embodied cognition, Lynott and Connell (2009) hypothesize that words expressing more strongly perceptual concepts should be processed more ef ciently than those expressing less perceptual concepts and developed a new measure: ***perceptual strength***. Participants are asked to rate the extent to which they experience the referent of a word through each of the ve external senses (hearing, seeing, smelling, tasting, and touching). Some evidence suggests that the maximum perceptual strength rating for a word (i.e., the strength rating found in the dominant sensory modality for that word) provides a better predictor of word processing

advantages than either concreteness or imageability (Connell & Lynott, 2012).

Taken together, this body of research indicates that there are important differences between concrete and abstract concepts. Questions remain concerning whether these differences are unified by a single underlying cause or etiologically diverse; whether they are qualitative or quantitative; and whether they are due to internal features of our concepts or to external processing factors.

Grounding Abstract Concepts: Early Approaches

Responding to concerns that abstract concepts may pose special problems for embodied cognition, early supporters of embodied cognition generally sought a single unified theoretical solution to abstract concepts. They often speculated that abstract concepts are fully grounded in affective and sensorimotor systems (e.g., Barsalou, 1999). Contemporary researchers, though, generally recognize that the heterogeneity of abstract concepts makes a multifront, divide-and-conquer strategy more promising (Bolognesi & Steen, 2018; Borghi et al., 2018).

Perhaps the earliest attempt to provide an approach to abstract concepts that is grounded in sensory and motor systems turned on an appeal to conceptual metaphors (Lakoff, 1987; Lakoff & Johnson, 1980). Conceptual metaphor theory (CMT) holds that we often understand abstract conceptual domains in terms of other experientially grounded domains. For instance, the concept of AFFECTION might be understood in terms of the concept of WARMTH. The primary evidence for this approach is our use of linguistic metaphors, but it is also supported by behavioral studies. For instance, spatial representations have been implicated in temporal judgments (Boroditsky & Ramscar, 2002; Casasanto & Boroditsky, 2008) and image schemas with a specific spatial orientation have been implicated in the comprehension of abstract verbs such as ***argue*** and ***respect*** (horizontal for the former and vertical for the latter; Richardson et al., 2003).

As a general account of abstract concepts, CMT has a number of significant problems. The relatively late emergence of linguistic metaphor in child development undermines its explanatory potential (Dove, 2009, 2016). Some (e.g., Grady & Ascoli, 2017) have argued that we need to distinguish primary conceptual metaphors that underlie common, nearly universal metaphorical patterns (such as DIFFICULT IS HEAVY or IMPORTANCE IS SIZE) from more complex, culturally specific ones (such as TIME IS MONEY or THEORIES ARE BUILDINGS). Whether or not this is a principled distinction, the fact that primary metaphors are thought to underlie multiple distinct concepts undermines the suggestion that they could provide a full explanation of the content of those concepts. In addition, the brain imaging evidence examining conceptual metaphors is inconsistent and suggests that their use may be context- and task-dependent (Kuhnke et al., 2020).

A second early approach focused on the importance of action schemas (Glenberg & Gallese, 2012; Glenberg & Robertson, 1999). The core idea behind this approach is that abstract language is often grounded in motor processes. One source of evidence for this approach is the action–sentence compatibility effect or ACE (Glenberg & Kaschak, 2002). Glenberg and Kaschak found that reaction times decreased when response direction (a button press either away/toward the body) and the implied direction of either concrete action sentences (e.g., ***Andy gave you the pizza/You gave Andy the pizza***) or abstract transfer sentences (e.g., ***Liz told you a story/You told Liz a story***) matched. They suggest that the ACE is the result of competition for resources by the motor planning associated with the action and the language processing associated with the sentence. This idea is supported by neurophysiological evidence that both object-transfer and abstract-transfer sentences modulate motor system activity (Glenberg et al., 2008).

As was the case with metaphor, the question of scope looms large. For one, some evidence suggests that the relevant activation of the motor system might be task-dependent (Tomasino et al., 2008). For another, it is far from clear that all abstract concepts are as intimately connected to motor activity as the concept of transference. Even if we limit ourselves to concepts that enjoy this sort of connection, questions remain concerning the extent to which action schemas can

provide a full account of the relevant concepts. After all, there are important differences between concrete and abstract forms of transference. These differences need to be explained, and it is hard to see how they can be captured by the motor system alone.

It is worth emphasizing that this is not a new problem. One of the early objections to the idea of perceptual symbol systems (Barsalou, 1999) was that perceptually based representations are not fine-grained enough to capture certain concepts. For instance, ***forging*** and ***signing*** a check involved the same motor movements and are visually identical (Anderson, 2005). One response to this objection is to propose that the relevant simulations would be similar with respect to how they are represented in the motor and visual systems but would differ in terms of how they are represented in other grounded systems, particularly those associated with internal experiences (Barsalou, 2008).

In keeping with this response, a third approach proposes that abstract concepts involve situated simulations (Barsalou, 1999, 2009). On this approach, conceptual simulations do not occur in isolation but instead include background settings, events, and even introspective responses. For example, instances of the concept BICYCLE would involve the simulation of our experiences of bicycles in relevant real-world situations. This approach was initially supported by a study in which participants generated typical properties for three abstract concepts (TRUTH, FREEDOM, and INVENTION), three concrete concepts (BIRD, CAR, and SOFA) and three intermediate concepts (COOKING, FARMING, and CARPETING; Barsalou & Wiemer-Hastings, 2005). This study had two core findings: (1) participants generated situational properties with both concrete and abstract concepts and (2) participants tended to generate more event and introspective properties with abstract concepts. The authors proposed that abstract and concrete concepts are generally associated with different aspects of situations: abstract concepts tend to focus on social aspects while concrete concepts tend to focus on physical entities and actions. In a more fully realized experiment employing similar methodology, participants tended to produce fewer entity properties, more introspective properties, and more relational properties with abstract concepts than with concrete concepts (Wiemer-Hastings & Xu, 2005).

While this approach is promising, there is a sense in which it merely pushes the problem up a level. It remains possible—perhaps even probable—that there are important differences in the types of situations associated with abstract and concrete concepts (Davis et al., 2019). There is no obvious a priori reason to assume that the relevant concepts tied to these disparate situations can be captured solely by means of grounded representations. This raises the question of whether an appeal to situated simulations reflects a unified theoretical solution to the problems posed by abstract concepts or simply a relabeling of them.

Recently, Barsalou et al. (2018) have argued that we need to abandon the distinction between concrete and abstract concepts because it is no longer useful. Part of their reasoning depends on the recognition that concrete concepts can vary greatly in how they are grounded (Kiefer & Barsalou, 2013). They propose that the abstract concepts are likely to vary in a similar way. An expanded property generation study provides some support for this (Harpainter et al., 2018). Participants listed properties for 296 abstract concepts and hierarchical cluster analyses revealed three main subgroups: a cluster dominated by sensorimotor features, a second dominated by internal states, emotions, and social relations, and a third dominated by verbal associations. Barsalou et al. (2018) suggest that concrete/abstract distinction should be replaced by two different distinctions that would apply to all types of concepts: the distinction between external and internal situational elements and the distinction between situational elements and situational integrations. This proposal fits with other attempts to disentangle a general problem of abstraction or generalization from the distinction between concrete and abstract concepts (Dove, 2016; Myachykov & Fischer, 2019).

Our admittedly quick foray into early grounded explanations of abstract concepts supports two initial conclusions. The first is that any successful account of abstract concepts is likely going to have to appeal to distributed semantic circuits that include representations from multiple experiential modalities. The second is that the apparent heterogeneity of abstract concepts does not erase the challenges that they pose but, rather, multiplies them. I am going to proceed in this essay with the assumption that these initial conclusions are correct.

My focus will be on specific theoretical questions that emerge in their wake. Table 8.1 provides a quick summary of these research questions. Each will be discussed in a separate section below.

Table 8.1 Central research questions concerning abstract concepts

	Key citations	Suggestive findings
Are concrete and abstract concepts handled by different neuromechanisms?	Binder et al. (2009), Papagno et al. (2009), Wang et al. (2010)	Semantic tasks involving abstract concepts elicit greater activation in the left middle/superior ATL and the left IFG than those involving concrete concepts
Is there a qualitative distinction between abstract and concrete concepts?	Crutch (2006), Crutch et al. (2013), Duñabeitia et al. (2009)	Some neuropsychological patients are more likely to make associative semantic errors with abstract words and shared-feature semantic errors with concrete words
How important are emotions for abstract concepts?	Kousta et al. (2011), Vigliocco et al. (2014)	Many abstract words have more affective associations than concrete words, and this emotionality might explain some of the processing advantages found with abstract concepts
Does language play a special role in abstract concepts?	Andrews et al. (2009), Bruni et al. (2014), Steyvers (2010)	Language-based distributional data appears to be more helpful with abstract concepts than non-linguistic experiential data
Are abstract concepts more context dependent?	Davis et al. (2020), Hoffman et al. (2013), Schwanenflugel and Shoben (1983)	Abstract words tend to rate higher on measures of contextual flexibility than concrete words
Do abstract concepts involve amodal representations?	Lambon Ralph et al. (2010), Patterson et al. (2007), Pobric et al. (2007, 2010)	Patients with semantic dementia experience a progressive impairment of conceptual knowledge that cuts across modalities

Are Concrete and Abstract Concepts Handled by Different Neuromechanisms?

A presupposition held, implicitly or explicitly, by many embodied theories of abstract concepts is that there is no fundamental difference between how abstract and concrete concepts work. This presupposition is challenged by the existence of a diverse body of evidence suggesting that concrete and abstract concepts may be handled by different brain mechanisms.

A number of brain imaging studies, for example, implicate different cortical structures in the processing of concrete and abstract concepts. In one experiment, abstract nouns elicited greater activation in the left superior temporal and left inferior frontal cortex during a semantic similarity task, while concrete nouns elicited greater activation in a bilateral network of association areas (Sabsevitz et al., 2005). In another, simple sentences that contained pairs of abstract, concrete, or mixed (abstract-concrete and concrete-abstract) words were compared, and the abstract pairs engaged the left middle temporal gyrus while the concrete pairs engaged a frontoparietal network (Sakreida et al., 2013). In keeping with these findings, several studies find that abstract words elicit greater activation than concrete words in middle/superior regions of the left temporal lobe (e.g., Giesbrecht et al., 2004; Noppeney & Price, 2004; Sabsevitz et al., 2005) and inferior regions of the left prefrontal cortex (e.g., Fiebach & Friederici, 2004; Giesbrecht et al., 2004; Noppeney & Price, 2004; Sabsevitz et al., 2005). Meta-analyses suggest that these areas are the most likely to show increased activation with abstract concepts (Binder et al., 2009; Wang et al., 2010).

There is some indication that these left frontal and temporal areas are functionally relevant to semantic processing. For instance, accuracy on a lexical decision task decreased with abstract concepts when repetitive transcranial magnetic stimulation or rTMS was applied over the left inferior gyrus and when it was applied over the left superior temporal gyrus (Papagno et al., 2009). A similar interference effect for concrete concepts was found when rTMS was applied over the right superior temporal gyrus.

Cognitive neuropsychological case studies provide further evidence that abstract and concrete concepts are partially supported by distinct neuroanatomical areas. A number of case studies report a greater impairment for the processing of abstract words than for the processing of concrete words following left hemisphere damage, including patients who present with aphasia (Goodglass et al., 1969), deep dyslexia (Coltheart et al., 1980; Franklin et al., 1995), and deep dysphasia (Katz & Goodglass, 1990; Martin & Saffran, 1992). Reverse concreteness effects have been found in patients with herpes simplex encephalitis (Sirigu et al., 1991; Warrington & Shallice, 1984) and

patients with semantic dementia or SD, a neurodegenerative disease that primarily affects the anterior and inferior portions of both temporal lobes (e.g., Bonner et al., 2009; Yi et al., 2007; although this pattern may not be a typical feature of semantic dementia: Hoffman & Lambon Ralph, 2011). In keeping with the reverse concreteness effects found in SD, patients who have undergone a selective unilateral anterior temporal resection (in either the right or left hemisphere) exhibit a reverse concreteness effect when their performance was compared to healthy controls and a group of patients with a more general semantic impairment (Loiselle et al., 2012).

This admittedly brief review of the neurocognitive and neuropsychological evidence suggests that the major brain areas that most reliably exhibit greater activation with tasks involving abstract concepts are the left middle/superior ATL and the left IFG. This conclusion needs to be tempered by the fact that the neuroimaging results are somewhat variable (Mkrtychian et al., 2019). Some studies even find activation in the ventral ATL that is specific to ***concrete*** concepts (Peelen & Caramazza, 2012; Robson et al., 2014; Visser et al., 2012). An argument can be made that a more fine-grained accounting of the neural circuits involved in processing concrete and abstract concepts is needed and perhaps even forthcoming (Montefinesse, 2019).

A further potential weakness of this body of evidence is that many of the relevant studies are—by design—aimed at uncovering the differences in the brain patterns elicited by abstract and concrete concepts (Dreyer & Pulvermüller, 2018). The search for contrasting activation patterns can lead investigators to miss overlapping ones. Studies that are not focused on these differences might well find interesting similarities between the activation patterns associated with both types. In keeping with this possibility, Pexman et al. (2007) find that both concrete and abstract words elicit activation in sensorimotor systems, but abstract words are associated with more widespread cortical activation, including temporal, parietal, and frontal regions previously associated with semantic processing.

Is There a Qualitative Distinction Between Abstract and Concrete Concepts?

Different theories characterize the abstract/concrete distinction in different ways. One approach proposes that many of the observed differences in processing efficiency between concrete and abstract concepts can be explained by the degree to which concrete concepts have richer and more detailed semantic representation (Plaut & Shallice, 1993). A number of studies have indicated that words with more associated semantic information are processed more efficiently in word recognition tasks than words with less associated semantic information (Pexman, 2012). Semantic-richness effects have been found in relation to several dimensions, such as number of features, semantic neighbors, and contexts (Duñabeitia et al., 2008; Schwanenflugel & Shoben, 1983), and this has led some researchers to offer multidimensional accounts of conceptual structure (e.g., Pexman et al., 2008; Yap et al., 2012).

One difficulty with appealing to semantic richness as a defining feature of the abstract/concrete distinction is that not all measures of semantic richness are created equal. Evidence suggests that object-related properties such as the number of features associated with a concept facilitate lexical decision tasks in a manner that is distinct from language-related properties such as semantic neighborhood density (Pexman et al., 2008; Yap et al., 2012). For example, number of semantic neighbors (but not number of features) facilitates the processing of abstract concepts in lexical decision and naming tasks while number of features (but not number of semantic neighbors) facilitates the processing of concrete concepts in those same tasks (Recchia & Jones, 2012). A common feature of the semantic-richness research is that the effects associated with different semantic dimensions are often task-dependent (Hargreaves & Pexman, 2012; Zdrazilova & Pexman, 2013).

Crutch and Warrington (2005) propose that concrete concepts are organized primarily around similarity and abstract concepts are organized around semantic association. Their qualitatively different representations theory builds on a body of neuropsychological

evidence (Crutch et al., 2013). For example, deep dyslexics were more likely to make associative semantic errors with abstract word targets and shared-feature semantic errors with concrete word targets (Crutch, 2006). These differences are difficult to explain in terms of quantitative factors such as semantic richness. Although the qualitatively different representations framework is based primarily on neuropsychological case studies, it is supported by some behavioral research on neurotypical individuals (Crutch & Jackson, 2011). In an eye-tracking experiment, participants presented with visual displays that included a target picture of an item that was a semantic associate of an abstract or concrete word tended to fixate more (and earlier) on depicted objects that were associates of abstract words (Duñabeitia et al., 2009).

A word of caution is warranted, though. The rationale for the qualitatively different representations theory rests primarily on case studies involving a relatively small number of participants who as a rule have fairly extensive lesions (Crutch, 2006; Crutch et al., 2013). This raises the likelihood of confounds or alternative explanations of the observed impairments. It is also important to note that some neuropsychological studies have failed to support this approach (Papagno et al., 2013; Skipper-Kallal et al., 2015).

How Important Are Emotions for Abstract Concepts?

A controversy has emerged concerning role of emotions in abstract concepts. Strikingly, many of the experiments cited in support of embodied cognition fail to manipulate emotionality even though many theorists who have committed the multimodal character of conceptual embodiment propose that concepts are partially grounded in affective systems (e.g., Barsalou, 2008; Fischer & Zwaan, 2008; Gallese & Lakoff, 2005).

The potential role of emotions in abstract concepts has become an important issue because there has been recent evidence of emotionality effects (which are analogous in many ways to concreteness effects). In particular, emotional valence—negative or positive—has been shown to facilitate lexical processing (Newcombe

et al., 2012). When age of acquisition, context availability, familiarity, imageability, and other variables are controlled for, abstract words have been found to exhibit a reaction time advantage over concrete words (reversing the usual concreteness effect; Kousta et al., 2011). The authors theorize that this reverse concreteness effect might be due to the overall tendency for abstract concepts to have a greater emotional content. Building on this idea, the Affective Embodiment Account (AEA) holds that emotion systems play a dominant role in the grounded representation of abstract concepts. A regression analysis of a diverse set of 1,446 English words finds that abstract words have a general tendency to have more affective associations than concrete words (Vigliocco et al., 2014). Abstract words also engage the rostral anterior cingulate cortex (rACC)—an area associated with emotion processing—to a greater extent than concrete words (Vigliocco et al., 2014).

Although abstract concepts as a group may have more emotional content than concrete concepts, many abstract concepts do not appear to be grounded emotional experience (e.g., mathematical and scientific concepts). A recent meta-analysis of brain imaging studies finds differences in the cortical activation patterns elicited by numerical and emotional concepts from those elicited by other abstract concepts (Desai et al., 2018). Given this, it seems reasonable to question the degree to which the distinction between abstract and concrete concepts can be reformulated in terms of the contribution of the emotions (Dove, 2014; Shallice & Cooper, 2013). Notice that acknowledging this point does not deny the possibility that particular abstract concepts are tied to emotions (Dreyer & Pulvermüller, 2018).

Some of the specific details of the cited studies may undermine their support for the AEA. For example, these studies generally match concrete and abstract words on imageability. Emotion words, though, tend to be rated as both abstract and imageable (Altarriba & Bauer, 2004). Matching stimuli on imageability may thus lead to an unrepresentative set of highly imageable abstract words (Skipper & Olson, 2014). These studies also generally hold age of acquisition constant. This could also be problematic because abstract concepts are often acquired later in development than concrete concepts (Barca et al., 2017; Borghi et al., 2018). One variable not controlled for in these

studies is hedonic valence. Indeed, the abstract words used in them were rated as higher in valence than the concrete words. This raises the question of whether or not valence is a confound of concreteness. Skipper and Olson (2014) controlled for these variables and made two important findings: (1) the rACC responded to emotional valence and (2) it responded more to concrete concepts than abstract ones (reversing the effect observed by Vigliocco et al., 2014).

The story is also complicated by the apparent relevance of action systems to the processing of abstract emotion words. Abstract emotion words elicit increased activity in the same areas activated somatotopically by face words (Dreyer & Pulvermüller, 2018; Moseley et al., 2012). Given that facial movements are important for emotion expression and detection, we have reason to think that they might play a role in the simulation of emotion concepts. In keeping with this, there is evidence that the motor system is causally relevant to the semantic processing of these concepts. A patient with a focal brain lesion in the supplementary motor cortex has been found to be particularly impaired in abstract-emotional word processing (Dreyer et al., 2015).

People with an autism spectrum condition (ASC) often demonstrate alexithymia – a difficulty with identifying and describing emotions in one's self and in others (Tager-Flusberg, 1992). An event-related fMRI experiment involving high-functioning individuals with an ASC found selectively reduced activation in motor areas for emotion words when compared with matched control words (Moseley et al., 2015). Although this evidence is merely correlational, the observation that individuals who are members of a population that generally struggles with emotion words exhibit hypoactivation of the motor system while processing them is suggestive.

Another potential explanation for the data used to support the AEA is also available. Lenci et al. (2018, p. 550) point out that the affective content of abstract concepts could be a "byproduct of co-occurrence statistics." In support of this hypothesis, they show that abstract words in Italian (even ones that do not have high-emotive value) tend to co-occur with contexts of higher emotive values. This evidence raises the possibility that linguistic associations may also play an important role in abstract concepts—including those with affective content.

The possible links between abstract concepts and both the motor system and emotionally laden verbal contexts suggest that the AEA may not provide a comprehensive account of abstract concepts. Instead, these links provide support for a multimodal approach in which abstract concepts are handled by distributed neural circuits. Emotions remain a somewhat neglected factor in abstract concepts, but they are unlikely to be a panacea for the broader challenges that abstract concepts pose to embodied cognition.

Does Language Play a Special Role in Abstract Concepts?

A number of researchers propose that language contributes to our conceptual system. The following is a list of some of the specific theories that embrace this idea within the context of grounded cognition (the list is alphabetical relative to their respective acronyms): Embodied Conceptual Combination or ECCo theory (Lynott & Connell, 2010), Language and Situated Simulation or LASS theory (Barsalou et al., 2008), Language and Associations in thinking or LASSO theory (Tillas, 2015), Language is an Embodied Neuroenhancement and Scaffold or LENS theory (Dove, 2019), Symbol Interdependency or SI theory (Louwerse & Jeuniaux, 2010; Louwerse, 2011, 2018), and Word as social Tool or WAT theory (Borghi & Cimatti, 2009; Borghi et al., 2019). These theories vary with respect to the importance that they assign to the language system. Some view language as merely a scaffold for our concepts (Vygotsky, 2012/1934). The LASS theory, for example, treats language as a cognitive shortcut for embodied or grounded conceptual processing. Others view language as central to our concepts. The SI approach (Louwerse, 2011; 2018) holds that linguistic information plays a dominant role in conceptual processing. Still others build on the idea that language may provide a unique source of information among other sources (Connell, 2019; Davis & Yee, 2018). To give an example, the WAT theory (Borghi & Binkofski, 2014; Borghi et al., 2019) emphasizes that words serve as social and cognitive tools while recognizing the importance of nonlinguistic embodiment and grounding.

Most of these theories hold a cognitive conception of language—that is, they maintain that language is not merely a vehicle for communicating our thoughts but also a means of furthering our capacity to have and formulate thoughts. Neuropsychological case studies provide an initial motivation for this view. For instance, aphasic patients often experience difficulty with categorization tasks that required the identification of a specific attribute shared by different items rather than a global comparison between them (Cohen et al., 1980; Semenza et al., 1992). The patient identified as LEW, for example, struggles with taxonomic classification tasks that involve a single dimension (such as shape or color) but not with thematic classification tasks that involve broader comparisons (Davidoff & Roberson, 2004; Roberson et al., 1999). When the performance of a group of aphasic participants was compared with age and education matched controls on a categorization task, the aphasic participants experienced greater difficulty when the criterion was "low-dimensional" (e.g., things that are green) than when the criterion was "high-dimensional" (e.g., farm animals) and the degree of their impairment was correlated with the degree of their anomia (Lupyan & Mirman, 2013). In a related experiment with neurologically intact participants, a similar selective impairment for taxonomic categorization and not thematic categorization was induced by means of a verbal interference task (Lupyan, 2009). These studies suggest that labels may make concepts for certain categories more accessible and resilient (Lupyan, 2012).

Another source of evidence for cognitive conception of language is the success of distributional models that treat concepts in terms of knowledge of statistical patterns derived from spoken and written language (Blei et al., 2003; Landauer & Dumais, 1997; Lund & Burgess, 1996). The core idea behind these models is that the meaning of a word is in part constrained by the company it keeps (Firth, 1957). They assume that semantic relatedness can be gleaned from aggregating the linguistic contexts in which a given word appears and have been shown to perform remarkably well on lexical access and lexical similarity tasks (Louwerse, 2011).

Recognizing that linguistic and non-linguistic experiences can be viewed as independent, yet complementary, sources of information

about the world, several researchers have proposed that we should adopt a hybrid approach that combines grounded simulations and distributional knowledge (Andrews et al., 2014; Louwerse & Jeuniaux, 2010; Riordan & Jones, 2010). Andrews et al. (2009) hypothesized that language-based distributional data is likely to be more helpful with abstract concepts than non-linguistic experiential data and developed a model that statistically combined these types of data. The model's performance on several cognitive tasks correlated with previously gathered behavioral evidence better than models that exclusively relied on linguistic or nonlinguistic experiential data (for further evidence of the advantages of hybrid models see Bruni et al., 2014; Steyvers, 2010). The success of this integrated model suggests that the ability to take advantage of the distributional information contained within natural language would be a useful enhancement to an experientially based conceptual system. It fits with behavioral studies that identify independent language-based and embodied factors in conceptual processing (Barsalou et al., 2008; Harpainter et al., 2018; Louwerse & Jeuniaux, 2010).

Perhaps the most compelling reason to think that language plays an important role in abstract concepts is that two of the brain areas that reliably exhibit increased activation in response to abstract concepts —the left superior ATL and the left IFG—have been linked to the language system. The left superior ATL has been linked to high-level speech perception and sentence comprehension (Humphries et al., 2006; Vandenberghe et al., 2002). Some researchers have proposed that it is involved in sentence-level compositional semantic processing (e.g., Hickok & Poeppel, 2004). The left IFG (which includes Broca's area) has been linked to several types of language processing, including auditory-verbal short-term memory, and has been associated with the inhibition of contextually present irrelevant verbal information (Badre & Wagner, 2005; Thompson-Schill et al., 2002). Several researchers have proposed that it plays an important role in the retrieval and selection of semantic knowledge (e.g., Jefferies et al., 2006).

Are Abstract Concepts More Context-Dependent?

Traditionally, cognitive scientists have viewed concepts as relatively invariant representations that are retrieved automatically in response to cognitive tasks (Machery, 2009). This view is challenged by growing evidence that conceptual representations may vary with stimulus (Sidhu et al., 2014; Taikh et al., 2015), task (Connell & Lynott, 2014; Pexman et al., 2008), and context (Lebois et al., 2015; Yee et al., 2012). Many contemporary theories of concepts embrace both embodiment and contextualism (e.g., Barsalou, 2016; Casasanto & Lupyan, 2015; Connell & Lynott, 2014). Against this background, it is important to address the observation, which dates at least as far back as Aristotle (1995), that abstract concepts tend to be more context-dependent than concrete concepts. Because abstract concepts are less directly tied to our immediate experiences of category members, their referents tend to be more dispersed across contexts (Davis et al., 2020; Wilson-Mendenhall et al., 2013).

One of the early explanations of concreteness effects sought to explain them in terms of differing degrees of ***context availability*** (Schwanenflugel & Shoben, 1983; Schwanenflugel et al., 1988). This measure is typically formulated in terms of the subjective ease to which participants can think of a specific context for the use of a word. According to the context availability theory, we have more difficulty generating plausible contexts in which abstract concepts might be used than we do with concrete concepts. The idea of context availability was initially formulated within a traditional amodal approach, but it has been repurposed within an embodied approach by supporters of the situated conceptualization framework (Barsalou, 2009; Barsalou et al., 2018). We should keep in mind, though, that some evidence suggests that concreteness and context availability might be distinct, orthogonal factors in conceptual processing (Holcomb et al., 1999; Levy-Drori & Henik, 2006).

Researchers have developed other measures of contextual flexibility. For example, ***semantic diversity*** is a measure of the degree to which a word is used in different linguistic contexts (Hoffman et al., 2013). Abstract words tend to rate higher on this measure than concrete words. For example, the word ***spinach*** tends to occur in contexts relating to cooking and eating and receives a relatively low semantic diversity rating while the word ***life*** can occur in a number of

different contexts (e.g., ***life on earth***, ***life sentence***, ***shelf life***, ***life of the party***, and ***stage of life***) and receives a higher rating (Hoffman, 2016). Semantic relatedness tasks appear to take longer with words that have high semantic diversity irrespective of imageability (Hoffman & Woollams, 2015). Admittedly, semantic diversity has a potential weakness: it applies only to words and their linguistic contexts. It may be the case, therefore, that semantic diversity merely provides an indirect measure of a deeper property of abstract concepts.

We need to keep in mind that many concepts are not linguistically encoded. One can have a concept of schadenfreude or umami before learning the relevant terms. Some researchers have made an effort to develop more direct measures of context dependence than semantic diversity. For instance, Davis et al. (2020) propose that abstract concepts exhibit less ***situational systematicity*** than concrete concepts. Rather than focus on linguistic contexts, this measure focuses on "the ***real-world*** contexts in which a concept might be acquired and recognized" (italics in the original; Davis et al., 2020, p. 3). The idea is that situations to which abstract concepts apply tend to be more diverse than those to which concrete concepts apply. This approach fits well with evidence suggesting that abstract concepts contain some situation-based perceptual knowledge (McRae et al., 2018).

As we discussed above, a collection of studies using different investigative techniques suggest that the left IFG is more active during the processing of abstract concepts than it is in the processing of concrete concepts (e.g., Fiebach & Friederici, 2004; Noppeney & Price, 2004; Papagno et al., 2009). Two main theoretical accounts of the role that the left IFG appears to play in abstract concepts have been offered (Della Rosa et al., 2018). The first proposes that the left IFG engages a network of circuits associated with language processing (Goldberg et al., 2007; Wang et al., 2010). This account fits with the hypothesis that the neural representations of abstract concepts rely more on verbally encoded information (Borghi & Binkofski, 2014; Borghi et al., 2019; Dove, 2014, 2018, 2019). The second proposes that the left IFG handles the semantic control functions that enable the selection of appropriate aspects of meaning in a specific context (Fiebach & Friederici, 2004; Hoffman et al., 2015; Noppeney & Price, 2004). A recent fMRI study manipulated both imageability and context availability and, through a

conjunction analysis, found evidence that the left IFG was involved in two separate networks: one associated with low imageability located primarily in the left hemisphere and the other associated with low context availability located primarily in the right hemisphere (Della Rosa et al., 2018). The authors suggest that the left IFG is a "neural crossroads" that is involved in both the re-inement, elaboration, and integration of abstract concepts and the selection of contextually relevant meaning (p. 457). By these lights, the left IFG contributes both to the internal representation of abstract concepts and their contextual -lexibility.

Do Abstract Concepts Involve Amodal Representations?

Embodied theories of concepts come in different strengths (Meteyard et al., 2012). Strongly embodied theories hold that semantic representations are fully constituted by experiential simulations within primary affective and sensorimotor areas. Weakly embodied theories appeal to simulations but also leave room for higher-level modal, crossmodal, or even heteromodal representations. Such theories often acknowledge that a degree of abstraction takes place within and between modalities (Simmons & Barsalou, 2003; Vigliocco et al., 2004). Much of the -ield is moving in the direction of weak embodiment. Indeed, Dreyer and Pulvermüller (2018) declare strong embodiment to be a straw man position (for similar assessments see Barsalou, 2016; Pulvermüller, 2013). Among contemporary supporters of embodied cognition, the idea that concepts rely on a hierarchy of neural circuits that extend from modality-speci-ic areas up to multimodal areas located within association cortices has gained prominence (Binder & Desai, 2011; Simmons & Barsalou, 2003).

Against this background, there has been an active discussion of whether or not concepts might depend, at least in part, on amodal representations (Dove, 2009, 2011; Shallice & Cooper, 2013). Some of the strongest evidence for them involves the anterior temporal lobes (ATL). The ATL have been implicated in the representation of semantic knowledge using fMRI (Binney et al., 2010; Visser et al., 2011) and MEG (Marinkovic et al., 2003). Perhaps the most striking evidence for the

involvement of the ATL in our concepts, though, can be found in research on the syndrome of semantic dementia. SD is characterized by an atrophy of the ATL and a progressive impairment of conceptual knowledge (Patterson et al., 2007). Because this impairment cuts across modalities and involves both linguistic and nonlinguistic semantic knowledge, some researchers propose that the ATL serves as a semantic "hub" containing conceptual representations that arise from the integration of information from modality-specific areas (Lambon Ralph et al., 2010; Patterson et al., 2007). Further support for this idea is provided by studies that elicit a generalized slowing of conceptual processing through the previous application of repetitive transcranial magnetic stimulation (rTMS) to areas within the ATL (Pobric et al., 2010).

Some critics of embodied cognition point to the research on SD as providing support for an amodal approach to concepts (Mahon, 2015; McCaffrey & Machery, 2012). Their arguments have two primary weaknesses: First, they generally assume a very strong form of embodiment that requires invariance and full grounding in primary sensorimotor areas—that is, they assume the very sort of approach that Pulvermüller (2013) colorfully refers to as "misembodiment." While this industrial strength form of embodied cognition is falsified by the mere presence of any amodal representations in our concepts, we have already seen that many researchers favor a more moderate approach. The second weakness of these arguments is their failure to recognize that there are two competing accounts of the role played by the ATL: the hub-only view and the hub-and-spoke view (Pobric et al., 2010). On the hub-only view, the ATL is the primary locus of conceptual representation and sensorimotor areas are excluded from our concepts. On the hub-and-spoke view, the ATL and modality-specific regions both contribute to conceptual representation. Clearly, the hub-and-spoke view fits best with the evidence that implicates modality-specific experiential systems in our concepts.

Abstract concepts pose a specific challenge for hub-and-spoke theories of the ATL. Given the proposed function of amodal hubs, one would expect that they would play a central role in processing abstract concepts. Unfortunately, while a number of studies have found that the ATL respond to semantic processing in concrete concepts (Marinkovic

et al., 2003; Spitsyna et al., 2006; Visser et al., 2010), similar results with abstract concepts have been elusive (for a discussion see Hoffman et al., 2015). The hub-and-spoke view is also thrown into question by the existence of a subgroup of SD patients who exhibit a reverse-concreteness effect (Macoir, 2009). Together, the inconsistent imaging data and the occasional (relative) preservation of abstract concepts have led some researchers to question whether or not the ATL play an important role in abstract concepts (Bonner et al., 2009; Shallice & Cooper, 2013).

Some recent evidence suggests that there may be a way out of this theoretical bind. A distortion-corrected fMRI study found that activation in ventral and superior portions of the ATL was greater for abstract words than concrete words (Hoffman et al., 2015). This is consistent with the idea that different portions of the ATL might serve more specialized graded functions with the dorsolateral regions being more closely linked to auditory-verbal experiences and ventromedial regions more closely linked to visual experiences (Binney et al., 2012). In keeping with this proposal, a meta-analysis of functional neuroimaging studies of semantic processing ﬁnds that picture stimuli activated inferior regions of the ATL more than verbal stimuli, but verbal stimuli activated superior regions more than picture stimuli (Visser et al., 2010). In a study of congenitally blind participants, abstract words whose content lacks clear sensorimotor features (e.g., ***freedom***) and abstract words that depict predominately visual phenomena (e.g., ***rainbow***) elicit greater activity in the left dorsal superior ATL than other abstract words (Striem-Amit et al., 2018).

Clearly, further research is needed. Closer attention needs to be paid to the contribution of subregions of the ATL and how they might contribute to trans-modal processing. Furthermore, we need a full explanation of reverse concreteness effects. All in all, addressing these issues will likely require answering some of the other questions raised above—such as the neuroanatomical differences between abstract and concrete concept representation and the role of the language system in abstract concepts.

Conclusion

One might think that, because abstract concepts do not constitute a homogeneous class, they do not constitute a substantial problem for embodied or grounded cognition. In this chapter, I have argued that abstract concepts are indeed heterogeneous but, as a result, raise a number of distinct theoretical and empirical challenges. These challenges can be expressed in terms of a series of questions: How should we characterize and explain concreteness effects? To what extent are they explained by emotions? Semantic richness? Context availability? Are abstract concepts processed differently than concrete concepts? If so, does this reflect quantitative or qualitative differences? How much does language contribute to our capacity for abstract concepts? Is it merely a scaffold or something more? Why do abstract concepts tend to exhibit a high degree of interpretative flexibility? How should we explain this flexibility in the context of an embodied or grounded view of concepts? Do abstract concepts depend on amodal representations?

Having raised these questions and critically assessed the available evidence that relates to them, we can now sketch the outlines of what a successful theory of grounded concepts might look like. Such a theory will likely appeal to distributed multimodal representations. It will likely hold that the emotions and the language system make important contributions to the representation of abstract concepts. It will likely involve a form of weak embodiment and adopt a hierarchical view of the neuroanatomical organization of concepts, both internal to, and across, specific modalities. Whether or not amodal hubs will play a significant role is not yet clear. A successful theory will also likely offer a contextualist explanation of the semantic flexibility of abstract concepts. In sum, although abstract concepts pose several distinct problems for embodied cognition, this does not rule out the possibility of a comprehensive account that addresses rich diversity of our concepts in general and abstract concepts in particular.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_9

9. Abstract Concepts and Metacognition: Searching for Meaning in Self and Others

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Abstract

Use of abstract concepts (e.g., truth) is one of the most sophisticated abilities that humans possess. Explaining how we develop this ability and how abstract concepts are represented constitutes one of the main challenges faced by theories of embodied and grounded cognition. In this chapter, we address this issue by focusing on the mechanisms underlying the processing of abstract concepts. We propose that metacognition—the set of capacities through which an operating subsystem is evaluated and represented by another subsystem—can ground the meaning of concepts, and that this grounding is particularly important for abstract concepts. In addition, metacognition can be applied to concept use itself. In this connection, the monitoring component of metacognition is particularly relevant: it can provide awareness of the inadequacies of our knowledge of abstract concepts, expressing a judgment of scarce con dence. This monitoring process can lead to two different but not mutually exclusive outcomes. We

propose that both these outcomes have an embodied counterpart, the activation of the mouth motor system. The first is the use of inner speech, which aims to search for possible further meanings and/or to further clarify the word meaning. The second is the preparation to request the help of other—better if authoritative—people (social metacognition): when our knowledge has gaps, the need of social deference is stronger.

Keywords Abstractness – Abstraction – Metacognition – Social metacognition – Grounding – Deference – Confidence – Monitoring

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Introduction: The Challenge of Abstract Concepts

Using abstract concepts like "truth" might seem very complicated. And yet, more than 70% of the words used by adults are above the median of abstractness and can be considered abstract words (Lupyan & Winter, 2018). How are we able to develop such a sophisticated ability, and to use complex words in such a fluent way?

For current theories of cognition, and especially for embodied and grounded approaches, explaining abstract concepts is still an open challenge (Borghi et al., 2017). It is much easier to demonstrate that concrete concepts (e.g., "chair") are grounded in the sensorimotor system than abstract concepts, since the latter seem more detached from perceptual experiences. It is important to consider some of the conclusions arising from discussion of the embodiment of concepts. First, contemporary approaches reject a dichotomous contrast between concrete and abstract concepts: even concepts that appear more concrete involve abstract aspects and vice versa. Second, multiple views of representation have shown that the meaning of abstract concepts relies not only on sensorimotor experience, but also on other forms of experiences linked to language use (Dove, 2014, 2018, 2019), sociality (Borghi & Binkofski, 2014; Borghi & Tummolini, 2020) and emotions (Newcombe et al., 2012; Vigliocco et al., 2014). Third, because abstract concepts are highly variable within and between individuals, it is crucial to study them in context rather than through isolated words (Barsalou et al., 2018).

Here, we focus on the mechanisms that might enable the complex ability to use abstract concepts. We will explore, in particular, the importance of metacognition for concepts in general and specifically for abstract concepts. After defining metacognition, we will illustrate its role at different levels. First, we will argue that metacognitive experiences and states can play an important but overlooked role in grounding the meaning of abstract concepts. Second, we will explore how metacognition can be applied to concepts themselves. We will contend that, because the meaning of abstract concepts generates higher uncertainty than that of concrete concepts, their use requires more extensive monitoring processes. These processes can be implicit, or they can have an explicit outcome leading to the use of external resources to reduce uncertainty. In the conclusions, we will also highlight the importance of studying the dynamics of abstract concepts' use in real-time interactions (see Fig. 9.1).

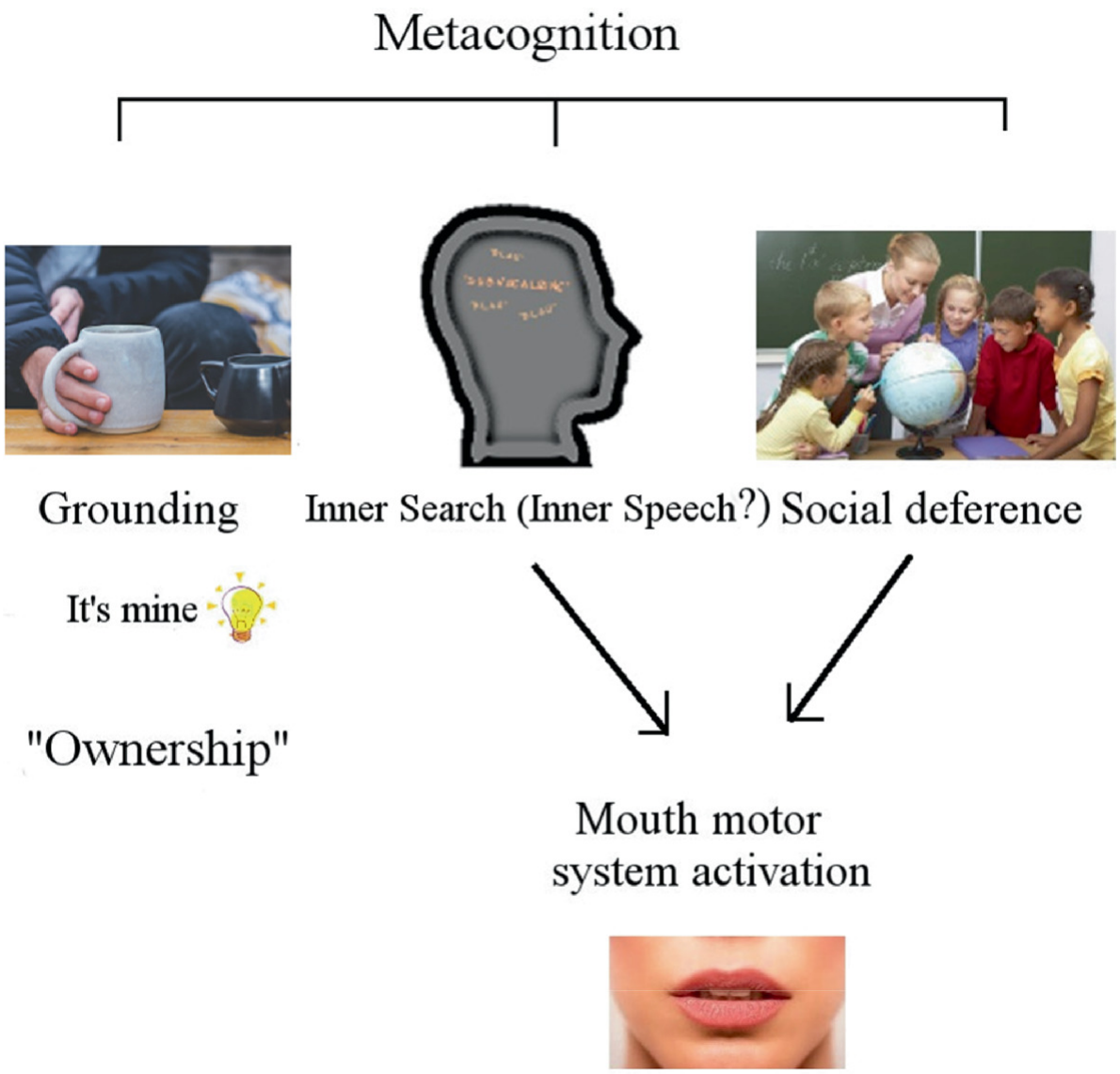


Fig. 9.1 Functions of metacognition relevant for abstract concepts: Grounding, inner search, and social deference

Metacognition: Grounding and Inner Search

Metacognition

Metacognition was classically considered as cognition about our own cognitive processes, "thinking about thinking" (Flavell, 1979) and "the monitoring and control of thought" (Martinez, 2006). Classical studies concerned how metacognitive strategies contribute to improving learning and memory. In keeping with this view, meta-memory and the implications of metacognition for learning and education were

extensively investigated (Hacker et al., 2009). Studies on reading and writing in children have often emphasized the important function of metacognition for mastery of such abilities. For example, it has been shown that four- to six-year-olds who are fluent readers adopt more efficient metacognitive strategies than poor readers: instead of focusing only on phonological aspects to overcome comprehension difficulties, they integrate semantic, syntactic, and phonological cues (Brenna, 1995). Similarly, metacognitive abilities are considered crucial for writing skills, up to the point that Hacker et al. (2009) have defined writing as a form of applied metacognition.

In recent years, metacognition has also been investigated in relation to error detection and to the strategy changes adopted following the discovery of errors, such as slowing down response times (Yeung & Summerfield, 2012). In this framework, metacognition does not refer only to higher order processes but more generally to "the set of capacities through which an operating subsystem is evaluated and represented by another subsystem in a context sensitive way" (Proust, 2012, p.4). It is a form of cognitive control in which one sensorimotor process implicitly represents a property of another (Shea et al., 2014).

Most studies have focused on two aspects of metacognition: the awareness of our cognitive processes and their control. Control processes involve two different components: the monitoring component (e.g., awareness of whether cognitive processes are used in an effective way) and the regulative component (e.g., adoption of strategies to improve and repair eventual knowledge failures) (Williams & Atkins, 2009).

In recent years other important areas of metacognition have also emerged. Many studies have focused on the relationship between metacognition and mindreading (e.g., Carruthers, 2009). Other studies have investigated meta-perception, that is, our judgments on how we are perceived by others (Lees & Cikara, 2019). Both areas can be relevant for abstract concepts—the first because of the importance of sociality for the acquisition and representation of abstract concepts, and the second because we might especially fear the judgment of others in relation to our competence in muddier and less clearly defined areas, such as those related to abstractness.

This chapter will address the relationship between metacognition and abstract concepts. We will start by proposing that metacognition can contribute to grounding of abstract concepts.

Metacognitive Grounding of Abstract Concepts

A basic tenet of embodied approaches to concepts is that our conceptual system is grounded in, and derives from, the perceptual and motor experiences that an organism recurrently has while interacting with its physical and social environment. According to one of the most influential theories (Barsalou, 1999; Barsalou et al., 2018), however, besides this well-explored sensorimotor grounding, concepts can also be grounded in the re-enactment of "introspective" states acquired during our experience ***with our own mind and body***.

Although the domain of introspective experiences—at least according to Barsalou—is on par with those of perception and action, it has received much less attention in the literature. One possible reason for this limited interest is that under the label of introspection, Barsalou originally included a disparate set of processes belonging at least to three different domains: ***motivational and affective information***, ***interoceptive information*** about the physiological condition of the body, and ***metacognitive information*** about other object-level mental states and processes like perception, memory, learning, reasoning, etc. Even if these domains of experience differ along multiple lines, their being primarily oriented to our inner world—and only indirectly to the outer environment—has motivated the conjecture that introspective experiences might be "central to the representation of abstract concepts" (Barsalou, 1999, p. 600). Recent evidence has provided empirical support to this conjecture showing that, relative to more concrete ones, abstract concepts might in fact be more grounded on affective (Vigliocco et al., 2014) as well as on interoceptive experiences (Connell et al., 2018; Villani et al., under review). These forms of experience might be related: for example, according to James (1884), emotions are given by the awareness of our interoceptive feelings. Still, whether and how metacognition can ground abstract concepts in a similar way has not been systematically explored.

Intuitively, the primary semantic domain where metacognitive information could play a grounding role is in that of ***mental state***

concepts since they explicitly bear meta-level content—that is, their content is about mental states. The domain of concepts like "belief", "desire", "intention", "decision", etc., is the one that we employ to explain and justify our own mental states and behavior as well as those of others during social interaction. This is the kind of explicit mindreading that children begin to systematically display from age four on (Apperly & Butterfill, 2009; Wellman et al., 2001), and which, while crucial to competently participate in our society, does not necessarily reflect the actual functioning of the cognitive system (Frith, 2012). Indeed, it has even been argued that the mastery of this conceptual domain does not originate in an intimate experience with one's own mind at all but is instead a culturally inherited skill acquired through expert tuition and verbal instruction (Heyes & Frith, 2014). Assessing this and related proposals on the development of explicit mindreading (for another recent view see Tomasello, 2019) is beyond the scope of this chapter, but they are still sufficient to suggest that the grounding of mental state concepts might be much less transparent than often assumed.

There are more subtle ways, besides concepts with explicit metal-level content, in which metacognitive signals might be used to ground conceptual representations. Consider, for instance, the formation of predictions—the monitoring of prediction errors and their control to minimize surprise—which is such a fundamental mechanism that it has been proposed as a unified principle of how the brain works at different hierarchical levels of organization (e.g., Friston, 2010). Signals monitoring errors in predictions and other mismatches are metacognitive signals (Shea, 2012). Since acquaintance with such (mis)match experience is available to infants from birth, if not before, it might be hypothesized that repeated metacognitive access to these internal events might actually lead to learning a "simulator" which can ultimately be used to ground high-level abstract concepts like "truth", "falsity", and any concept that entails a form of goal frustration like "anger" (Barsalou, 1999).

For another example consider how a basic understanding of "mine", "yours", and other concepts of property ownership might develop. Ownership of property has been considered as a prototypical abstract concept resisting an embodied explanation (Arbib et al., 2014) and a

full-fledged ownership concept is probably the sophisticated product of cultural dynamics. However, some of its sensorimotor foundation has been uncovered (Constable et al., 2011), and it has been argued that the semantic core of ownership is ultimately related to the notion of control (Furby, 1980; Scorolli et al., 2018), which is fundamentally unobservable (Langacker, 2009). Tracing a plausible cognitive development of this control-based view, Furby has hypothesized that concepts of possession and ownership develop as a byproduct of the intrinsic motivation of children to effectively interact with the environment ('competence' motivation, White, 1959). Importantly, Furby has proposed that, during their first two years of life, infants learn to identify the objects in their environment that occasion feelings of efficacy and personal control to keep them apart from those that instead thwart such feelings. From the child's perspective, the former class of controllable objects becomes the category of objects that are understood as "mine", while the latter one includes those that are not. Crucially, casting this proposal in contemporary computational frameworks of reinforcement learning reveals that such a curiosity-based exploration of new skills relies on monitoring one's competence improvement (or lack thereof), which is a fundamentally metacognitive learning signal (Gottlieb et al., 2013; Mannella et al., 2018). Thus, in principle, even metacognitive processes that monitor and control low-level cognitive processes can provide the kind of information that can be used to develop and ground higher-level abstract concepts.

Metacognition About Abstract Concepts: Current Literature

If metacognition about other target cognitive processes can ground abstract concepts, it can also be directed at concept use itself, and at the way we use abstract concepts in particular.

In the literature, the role of metacognition for concepts in general has not been systematically addressed. To our knowledge, the first proposal that directly links metacognition and concept use was advanced by Shea (2018, 2019). In his view, a concept has three potential sources of unreliability that may affect how it can be "used" in cognitive functioning: how much information it encodes, how

accurately it can categorize instances, and how "dependable" the concept is "as a basis for forming expectations" (Shea, 2019). A concept is more reliable the more correct expectations and the less prediction errors it generates. In his view basic level concepts not only maximize informativity and distinctiveness, they also elicit more expectations than superordinate level concepts. Notice, however, that lower level concepts might generate more expectations, but also generate a scarcer sense of con dence: for example, we might know what animals are, but we might not be able to de ne precisely what an ant-bear is.

These examples from Shea concern what we have called abstraction (Borghi et al., 2019; Borghi & Tummolini, in press). With "abstraction" we refer to the fact that some terms, such as superordinate concepts, are more general than others (e.g., "animal-dog"); with "abstractness" we refer to concepts such as "truth" and "freedom" that, differently from superordinates, do not activate a collection of single objects/entities. Elsewhere, we have claimed that abstractness and abstraction are interrelated but different.

Even if the relationship between metacognition and abstractness has so far received only scant attention (for exceptions, see Borghi et al., 2018; Shea, 2018), the role of metacognition has been underlined more generally for learning, including learning complex abstract abilities. One example is learning in the context of mathematical education. Holton and Clarke (2006), in their analysis of mathematical education, distinguish conceptual and heuristic scaffolding, i.e., scaffolding related to the content to learn or to the strategies to adopt. This scaffolding can be provided by an expert, it can be reciprocal—in collective work, for example—or it can be individual. In their view, self-scaffolding can be considered the same as metacognition.

In sum: the relationship between metacognition and abstractness has not yet been extensively addressed. We contend that this is crucial to do and will motivate why.

Abstract Concepts and Uncertainty

Consider two different scenarios of understanding language. Someone says to his/her partner: "Coming back from work I bought zucchini for dinner" vs. "I am nally free (from a harsh deadline)". We do not argue

that the first situation is entirely concrete and the second entirely abstract. In line with Barsalou et al. (2018), we think that the first statement involves some abstract elements: for example, the action of buying typically involves a monetary exchange, a buyer, and a seller. Similarly, the second situation is not completely abstract: it brings to mind a working place such as an office or factory the recipient will likely visualize that includes other actors such as a boss or colleagues with relations between them. Furthermore, both situations involve embodied aspects. However, in the first case it is easy to fix the reference of what has been said, while this is less true in the second case: what does it mean to be free? While in the first situation the concrete nature of the object referent might lead to a physical action of the recipient (or at least to its simulation), e.g., putting the zucchini in the fridge, the second will not. At the same time, an embodied response is possible in the second case too: the recipient might simulate the metacognitive experience of regaining a sense of agency, re-enacting interoceptive experiences. He/she might also start a linguistic action, by asking for clarifications, for example. In any case, in the second situation the listener/recipient is left with more uncertainty.

Consider now another example: the degree of uncertainty in the listener is higher if s/he hears "I saw an animal" compared to "a dog" or to "the dog of the neighbor". It is more difficult to prepare a (real or simulated) action toward an object/entity that is not clearly specified. This uncertainty rests on the fact that the literal content of the sentence is more difficult to resolve, it is harder to link to a specific referent, and the linguistic meaning does not directly evoke a physical action. This might be different in the case of language production. If we see a visually degraded object, we can be more confident in saying, "it is a vehicle" (superordinate) than a "Fiat 500". Confidence might indeed be higher in using a superordinate than a lower level category (see Fig. 9.2).



Fig. 9.2 Abstraction and abstractness in dialogue. Abstraction: When we see a degraded stimulus, as speakers we produce fewer prediction errors and feel less uncertain/more confident with superordinate than with basic and subordinate level concepts. In normal conditions, the level of confidence in the speaker instead is clearly higher with subordinate than with basic concepts. The case is different for the listener, for which the degree of confidence might be maximal at a basic level. Abstractness: both the speaker and the listener experience uncertainty/scarce confidence, although this uncertainty is more pronounced in the listener

The aforementioned examples refer respectively to what we have called abstractness and abstraction (Borghi et al., 2019), arguing that they are two interrelated and yet distinct processes. However, the

above examples show that both abstract and superordinate concepts ("freedom", "vehicle") generate higher uncertainty during word comprehension than concrete basic level concepts. A concrete basic level concept leads to less prediction errors and to a greater degree of confidence (Shea, 2019) in the listener.

Importantly, we are not claiming that implicit metacognitive evaluations only occur with abstract concepts. For example, we might be aware that the object in front of us is not a good member of the category "bottle" and we might not feel confident in forming a novel category. But the feeling of scarce confidence is likely more frequent with concepts whose referents are not clearly identifiable and perceptually bound. Take the notion of "metacognition" itself—we might be unsatisfied with its previous definitions, and be uncertain as to which processes belong to metacognition. The uncertainty on conceptual meaning might generate the need to learn more (Shea, 2019), a need that is particularly pronounced the lower our confidence in the conceptual meaning.

In our view more abstract words lead to a higher uncertainty, and this uncertainty has a double effect. On the one hand, we (at least implicitly) perceive this uncertainty, resulting in a confidence judgment. When we process abstract concepts, we might experience feelings of not knowing (or knowing) something, and tip of the tongue phenomena, all phenomena falling into the category of "procedural" metacognition (Proust, 2012). The outcome of these feelings results in continuing the search. That is, when we are uncertain about the linguistic meaning, we continue searching for it. This search for meaning can occur in multiple ways—for example by using an online search engine, or by consulting a physical dictionary. We propose that another important way in which this search for meaning occurs is through inner speech, which allows us to access a range of meanings or to re-explain to ourselves the possible meaning. We contend that the identification of the meaning of concrete concepts, due to the availability of their referents, is considered reliable, hence assigned more weight. Ease of processing and better recall of concrete compared to abstract concepts—the well-known concreteness effect (Paivio, 1990; Schwanenflugel et al., 1992)—are signals of higher reliability and confidence. Why would we use inner speech to search

for meaning? We hypothesize that using inner speech can play a predictive role, helping us to advance more possible alternatives, to better retain them in working memory thanks to the phono-articulatory embodied trace, and to better focus our attention. On the other hand, the feeling of scarce conﬁdence can lead us to search for a solution outside ourselves, through a linguistic action directed to others. We will address this process in the section titled Social Metacognition.

Uncertainty and Inner Speech: Supporting Evidence

Two sources of evidence support the idea that we continue searching for meaning when encountering abstract concepts.

The ﬁrst source of evidence is behavioral. We can ask participants to process concrete and abstract words using a task that interferes with inner speech in order to test whether this speech is activated: an ongoing inner speech process might reveal a further search for internal meaning. To explore this possibility, in a recent study (Zannino, Fini, Benassi, Carlesimo & Borghi, under review) we used articulatory suppression, asking participants to repeatedly pronounce a syllable at a fast pace while categorizing words as concrete or abstract. To control for possible dual-task interference, we employed both articulatory suppression and an additional, nonverbal condition (Alderson-Day & Fernyhough, 2015; Baldo et al., 2005; Lidstone et al., 2010) in which participants were required to manipulate a softball. In a ﬁrst experiment, we directly compared concrete and abstract concepts and found an interaction showing that articulatory suppression interfered more with processing abstract concepts, while the softball manipulation affected the processing of concrete concepts more. In a second experiment, we introduced a baseline condition. In line with our predictions, we found that articulatory suppression, but not the softball manipulation, had a selective effect on processing abstract concepts, slowing down response times compared to the baseline condition. This evidence suggests that inner speech plays a substantial role during processing of abstract concepts.

The second line of evidence comes from neuroimaging. Brain imaging evidence highlights that during processing of abstract concepts we generally experience uncertainty. Meta-analyses (Binder

et al., 2009; Wang et al., 2010) have revealed that compared to concrete concepts, abstract ones activate primarily left inferior frontal areas. Specifically, most studies report selective activation of the left inferior frontal gyrus (LIFG) (mostly pars orbitalis, Broca area). LIFG activation is generally associated with phonological processes, lexical retrieval, and subvocalizations, and its activation in relation to abstract concepts has been associated with a longer time maintaining these concepts in phonological short-term memory (Binder et al., 2005). A searching process would be activated, similar to the one occurring with non-words (Acheson et al., 2011): abstract words would be kept in working memory, in a cycle involving both phonological encoding and articulatory planning. This view does not posit any separation between language comprehension and production (Pickering & Garrod, 2013). In keeping with it, evidence has shown that silent word reading (Topolinski & Strack, 2009; Topolinski et al., 2014) involves covert articulation of their sounds.

This evidence is in line with our proposal that abstract concepts are characterized by higher uncertainty, and to higher difficulty in prediction: we search longer for the word meaning, also through inner articulation. We hypothesize that this process of inner search involving the articulatory component of inner speech is strictly linked to semantics. Participants use inner speech (Langland-Hassan & Vicente, 2018; Vygotsky, 1934) to continue searching and trying to clarify to themselves word meaning.

Metacognition and Abstractness: Supporting Evidence

So far we have shown through implicit tasks that with abstract concepts we might search longer for the word meaning. The question arises, whether we are also aware that metacognition is especially crucial for more abstract concepts. To test for this, in a recent study we asked participants to evaluate 425 abstract words on a variety of dimensions, including abstractness, concreteness, imageability, mouth and hand activation, involvement of the 5 senses, interoception, emotional arousal, sociality, metacognition, and social metacognition (we will describe this dimension in the section titled Social Metacognition) (Villani et al., 2019). Relevant to this chapter is the relationship between judgments of abstractness/concreteness and of

metacognition. Participants were required to evaluate the "metacognition valence" of words: they were told that their task consisted of rating how much the word evoked mental and cognitive processes or processes occurring in the brain more generally.

In line with our predictions, metacognition was positively correlated with abstractness ($r = 0.4$) and negatively correlated with concreteness ($r = -0.21$); it was also negatively correlated with age of acquisition and modality of acquisition ($r = -0.19$, $r = -0.22$, respectively), indicating that abstract terms scoring higher in metacognition were acquired later and through language more than through perception (Fig. 9.3). Metacognition was more strongly correlated to other dimensions related to inner grounding, such as emotional arousal ($r = 0.65$) and interoception ($r = 0.5$); it was also positively correlated with contextual availability ($r = 0.43$), with audition, taste, and mouth involvement ($r = 0.28$, $r = 0.16$, $r = 0.42$, respectively)—suggesting that the monitoring process might have a sensorial component—and with sociality ($r = 0.27$) and social metacognition ($r = 0.19$). Overall, these results indicate that participants tend to associate metacognition with conceptual abstractness.

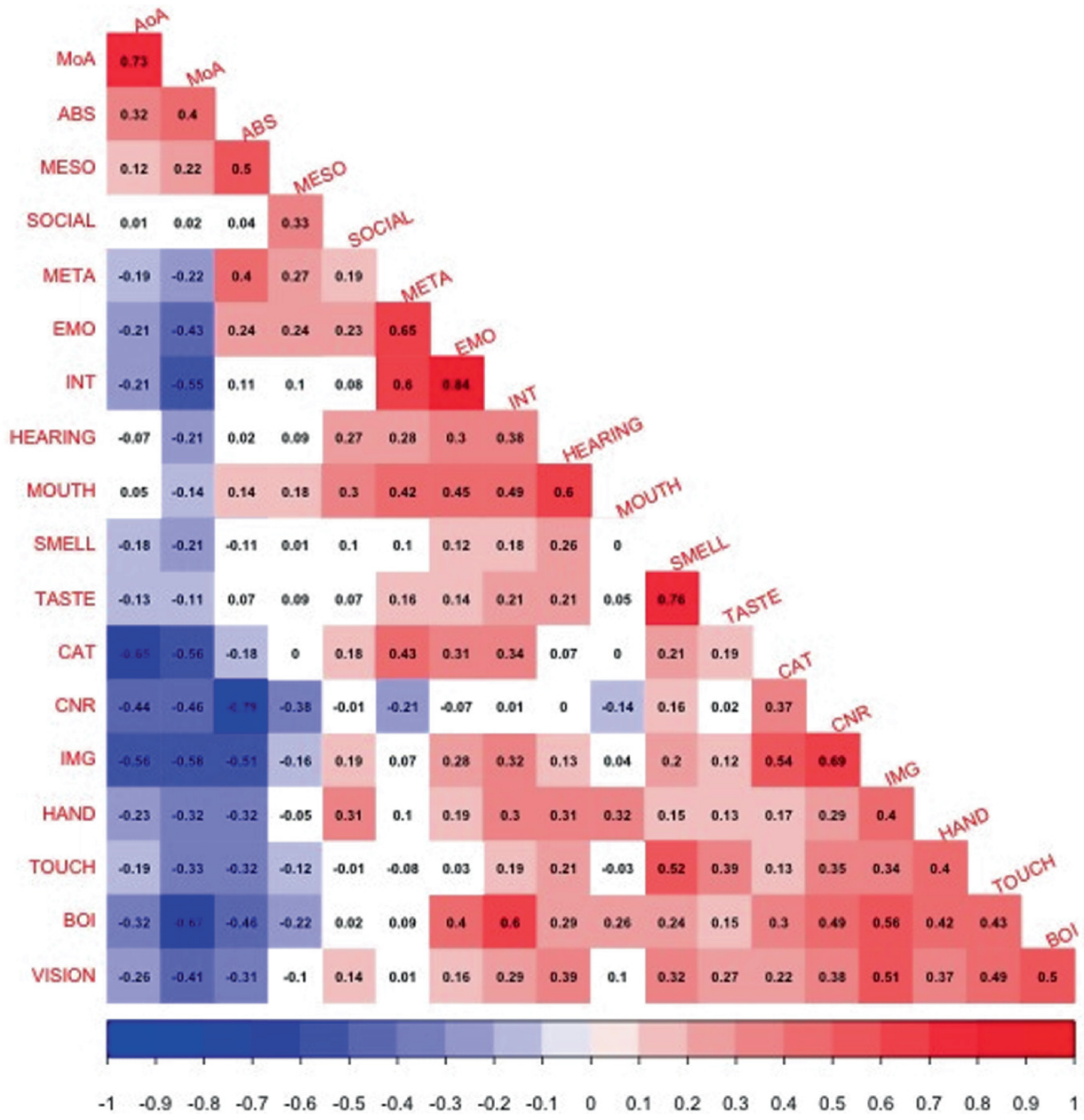


Fig. 9.3 Correlogram. Correlations between the different dimensions rated for 425 abstract concepts (from Villani et al., 2019). In red are positive correlations, in blue negative ones. The intensity of the red and blue colors indicates the strength of the correlation

Development of Metacognition, Acquisition of Abstract Concepts

Abstract words are acquired later than concrete ones. Age of acquisition ratings indicate that at the age of 4 less than 10% of known words are abstract; abstract vocabulary has a dramatic increase and reaches more than 40% of words by the age of twelve (Ponari et al.,

2018). In adults, words more abstract than the median represent more than 70% of the vocabulary (Lupyan & Winter, 2018). Interestingly, the pattern of development of abstract words has some similarities with that of acquisition of metacognitive abilities.

While according to early studies explicit metacognitive abilities (Proust, 2012) developed quite late, recent ones emphasize that even preschoolers older than three possess important metacognitive abilities such as the capability to regulate their thoughts and their emotional and affective states. Developmental studies provide some contrasting evidence, but all models postulate substantial improvement in metacognition during the first six years of life, with a dramatic increase at ages three to four. For example, Schraw and Moshman (1995) propose that six-year-olds already reflect on the accuracy of their knowledge, consolidating these abilities around eight to ten. Next appears the ability of regulating cognition, with a marked development around ages ten to fourteen. Relevant for us are studies linking metacognition with epistemological comprehension (Kuhn & Dean, 2004): around age four children start to acknowledge that one person might be right and another wrong and with adolescence they develop the diversity of opinions.

Overall, the pattern of development of metacognitive abilities seems to reflect that of abstract concepts, with a marked improvement around four to five years of age and then after eight (Ponari et al., 2018). One could speculate that the necessity to develop metacognitive abilities is among the causes of the later acquisition of abstract compared to concrete concepts.

Summary

Abstract concepts are more difficult than concrete ones, owing to their higher detachment from sensory modalities and to the fact that they refer to varieties of sparse situations rather than to a single, concrete referent. We propose that metacognition has a multifold function. First, it might provide an additional but often overlooked experiential domain to ground the meaning of abstract concepts. Second, using abstract concepts generates more uncertainty and less confidence, hence they require a more efficient and longer internal monitoring process than concrete concepts. Moreover, participants recognized the

link between metacognition and abstractness as revealed by ratings showing a correlation between the two dimensions. We argue that this monitoring process leads to a long-lasting inner search for meaning. External signals of this inner search can be found in longer times to process and recall abstract concepts (concreteness effect). We propose that the inner search for meaning likely occurs through inner speech. It might consist of considering a range of different meanings, or in clarifying to ourselves their possible meaning. Alternatively, this search for meaning might lead us to ask information of others, in order to fill our knowledge gap.

We will develop this issue in the next section.

Social Metacognition

System 2 Metacognition

So far we have discussed two main functions of metacognition with respect to abstract concepts: it can contribute to their grounding, and it has an important monitoring and regulating role. We will now discuss the cases in which metacognitive feelings of scarce confidence lead us to rely on others. Other people can help us to ground concepts thanks to their expertise (Prinz, 2002, 2012). Notice that we do not necessarily need to be aware of these metacognitive feelings of self-confidence, as long as the uncertainty signal is picked up by one system and fed into another that triggers the uncertainty reduction.

One influential proposal includes the characterization of "system 2 metacognition" (Frith, 2012; Shea et al., 2014). Indeed, "when sensorimotor systems have to be coordinated between two or more interacting agents" (Shea, 2014, p. 188) it is no longer possible to use internal, implicit metacognitive information. At the same time, inter-agent control would be more effective when relying on metacognitive representations. Shea et al. (2014) propose that system 2 explicit metacognition is not only for representing others' mental states (mindreading), but also for communicating the agents' metacognitive states themselves, e.g., their confidence. Experiments show advantages in joint actions when participants communicate their confidence to others (Fusaroli et al., 2012). System 2 metacognition renders metacognitive representations available for communication and can

lead to the individuation of solutions (e.g., finding an expert or an online source to arrive at the meaning). According to Shea et al., it is uniquely human and has evolved for supra-personal cognitive control to allow individuals to cooperate in sophisticated ways. Importantly, it can work both synchronically, when two people work on the same task, or diachronically to improve future task performance.

Let us apply this notion to a dialogue in which concrete and abstract words are exchanged. Both the speaker and the recipient implicitly refer concrete words to objects. With abstract words, the speaker and especially the recipient experience feelings of uncertainty and of scarce confidence, leading to prediction errors. When they fail to find the meaning of abstract concepts, they might revert to system 2 metacognition. System 2 metacognition can derive metacognitive information from the single systems, for example by relying on the degree of confidence reported by the involved agents.

Social Metacognition and Abstract Concepts

Frith (2012) and Shea et al. (2014) have highlighted the benefits of explicit metacognition in enhancing collaborative decision-making. Because of the complexity of abstract concepts, we have proposed that a mechanism similar to the one they illustrate is at play during use of abstract concepts (see also Shea, 2018). We have called it social metacognition (Borghi et al., 2018, 2019; Fini & Borghi, 2019). It consists of a process in which we monitor our concepts and, in cases in which we find they lack sufficient clarity and detail, we refer to others (Prinz, 2012; Shea, 2018). Its function is to detect eventual inadequacies of our knowledge and to induce us to prepare to ask information of others. We call it social because it can be seen as a bridge between ourselves and other people. This mechanism is both implicit and explicit. It is implicit because we are not (necessarily) aware of our knowledge gaps, even if we may have a general sense of scarce confidence in processing certain words. It is explicit because according to our hypothesis it leads us to prepare ourselves to ask information of others.

Social Metacognition and Reliance on Others: Supporting Evidence

We hypothesize that the higher the abstractness of words, the higher is the sense of scarce conﬁdence and the more we need others to support us. Recent evidence in our lab supports this hypothesis.

In a ﬁrst study (Fini, Era, Darold, Candidi & Borghi, submitted) participants were submitted to a concept guessing task: they were presented with pictures referring to situations linked to concrete/abstract concepts (e.g., bottle: to drink; freedom: to run on the grass) and they were required to guess to which word the image referred. When they were not able to infer the word immediately, they could ask a confederate for suggestions. Then participants had to rate to what extent they needed others in order to guess the concept associated with the blocks of abstract/concrete pictures. Abstract concepts were associated with signiﬁcantly higher values than concrete concepts, suggesting that when participants were asked to guess abstract concepts, they subjectively perceived the necessity to rely more on others' help.

The second study is one we previously described (Villani et al., 2019) in which participants were asked to rate 425 abstract words on different dimensions. Among the considered dimensions participants were also asked to provide a judgment of social metacognition: they were told that they had "to rate how much the linguistic competence of other people is useful for understanding the meaning of a series of words". Then the instructions continued: "Your task is to rate how much you think you need to consult other people to understand this word". Social metacognition correlated very strongly with abstractness ($r = 0.5$), with sociality ($r = 0.33$), with modality of acquisition (linguistic) ($r = 0.22$) and with late age of acquisition (late) ($r = 0.12$). A Principal Component Analysis (PCA) on the ratings led to a three-components solution, i.e., concreteness-abstractness, sensorimotor (ﬁve senses and hand), and inner grounding (sociality, metacognition, introspection, emotion, and mouth). Importantly, social metacognition was included in the abstractness-concreteness component: consistent with our hypothesis, abstractness was characterized by late age of acquisition, linguistic modality of acquisition, and social metacognition. It contrasted with concreteness, characterized instead by body object interaction (BOI, Siakaluk et al., 2008), higher contextual availability (Schwanenﬂugel et al., 1992), and higher

imageability (Paivio, 1990). These two studies clearly indicate across two different tasks that participants are aware that the help of others is needed in particular for more abstract words.

Embodied Social Metacognition

We propose that social metacognition has an embodied counterpart. When we become aware of the inadequacies of our knowledge, we prepare ourselves to ask information of others, pre-activating our mouth motor system. Whether this is an explicit, deliberate process or an implicit one is currently unclear. A variety of studies in our lab and in other labs have shown that, during processing of abstract concepts, the mouth motor system is activated. We will briefly summarize this evidence (see Fig. 9.4).

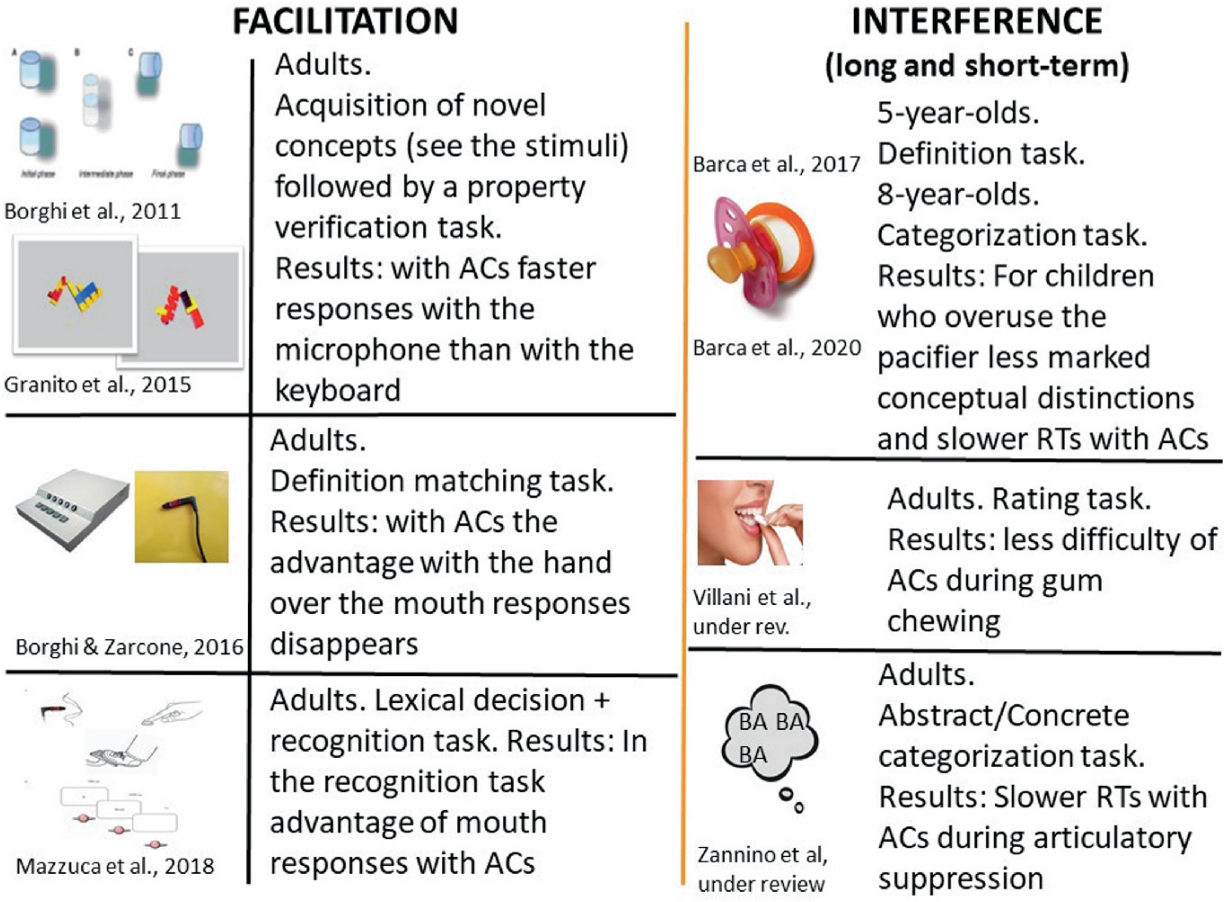


Fig. 9.4 Evidence on mouth activation. Participants, tasks, and results of each study. ACs = abstract concepts

In two studies we mimicked acquisition of concrete and abstract words using artificial stimuli. Participants first perceived and categorized novel stimuli, then they were taught their (novel) name. In the first study concrete words were operationalized as novel manipulable objects, in the second as nonmanipulable objects that interacted in novel ways (multiple referents). In subsequent feature verification tasks responses to concrete concepts were faster with the hand whereas response to abstract concepts were faster with the mouth (Borghi et al., 2011). In the second study (Granito et al., 2015), the members of concrete concepts consisted of perceptually similar objects and those of abstract ones having similar relations between their parts. After familiarization with the categories, half of the participants received linguistic training in which they had the meaning of the concept explained and were taught its novel name. In a subsequent categorical recognition task, the performance of participants who had received linguistic training was better for abstract than for concrete concepts. Furthermore, participants who had not received linguistic training provided faster responses with the hand than with the mouth, whereas this difference disappeared when participants had undergone linguistic training. Hence, these studies indicate that language was more crucial to learn novel abstract concepts than novel concrete ones and that linguistic training led to the activation of the mouth.

In further studies, we used real abstract and concrete words and found that mouth responses to abstract concepts were facilitated. When participants had to decide whether an explanation fits a target word or not, responses with the hand were faster with concrete words, whereas responses with the mouth (participants had to press a device with the teeth) were faster with abstract ones (Borghi & Zarcone, 2016). Mazzuca et al. (2018) did not find the interaction in a lexical decision task, but in a subsequent recognition task found that concepts were facilitated in the mouth compared to the hand condition. To demonstrate that the role of the mouth was constitutive for meaning comprehension, we also designed some interference tasks. Two longitudinal studies revealed that the use of a pacifier to impede active mouth movement had a long-lasting effect on abstract word acquisition. A definition task analysis of the conceptual relations

produced by six-year-olds revealed that the distinction between concrete and abstract concepts was less clearly marked for children who had used a pacifier beyond age three, even if their definition accuracy was not affected (Barca et al., 2017). In a categorization task performed by eight-year-olds, response times with abstract concepts, but not with concrete and emotional concepts, were slower the longer children had used a pacifier during infancy (Barca et al., 2020).

Another study in which we addressed metacognition and mouth activation with an interference paradigm is based on word difficulty ratings (Villani, Lugli, Liuzza, Nicoletti, & Borghi, under review). Difficulty ratings can be interpreted as metacognitive signals of scarce fluency. Participants rated the difficulty of concrete and abstract words and were concurrently submitted to four interfering conditions: a gum-chewing condition, in which participants actively involved the mouth, an interoceptive condition, in which they had to pay attention to their heartbeat, an articulatory suppression condition, in which they had to pronounce a syllable, and a softball manipulation condition. We predicted that the softball manipulation condition would particularly interfere with concrete concepts, whereas the other conditions would interfere more with abstract ones. We will discuss only results relevant to the hypothesis that processing abstract concepts involves the mouth. We found strong support of the hypothesis that the gum condition interfered more with abstract than with concrete concepts (animals and tools) when compared to the ball condition, even if the interference of the interoceptive condition was more marked. Contrary to our hypothesis, the articulatory suppression seemed to increase the difficulty of all verbal stimuli. The null result contrasts with the results obtained by Zannino et al. (in prep.) and is likely due to the fact that the task involves an explicit evaluation and does not take into account online performance.

Evidence for activation of the mouth motor system was also found in other laboratories. Ghio et al. (2013) found that participants rate that abstract concepts activate mouth and hand effectors; the mouth effector was evaluated as particularly relevant for mental state abstract concepts. Dreyer and Pulvermuller (2018) provide fMRI evidence for the activation of the mouth motor system, in particular for abstract concepts of mental states. Since mental state abstract concepts are

generally evaluated as particularly abstract, this evidence concurs in demonstrating that, the higher conceptual abstractness, the more the mouth motor system is activated.

Social Deference: Developmental Evidence

In order to rely on others to complement the gaps in our knowledge, we need to trust them and their knowledge. We also need to correctly identify which experts can help us. This is a complex ability that develops gradually.

Relevant in order to understand the role of deference—when, why, and how we refer to experts—are studies on causal understanding. Kominsky et al. (2018) argue that in order to select the right experts we need to have at least some information on causal mechanism, such as to know in an abstract way how a bike might work. The authors introduce the term "mechanism metadata", i.e., information on information concerning mechanisms of a given system. Metadata does not imply detailed information. They are more abstract and are compatible with fragmentary knowledge that is consistent across individuals with a similar exposure level and is present for every causal system people encounter. In some experiments they presented seven- to ten-year-olds and adults causally complex objects (e.g., microscope, TV) and found a relationship between causal complexity (including a high number and diversity of components) and the tendency to ask for help. They found that the sense of complexity extends from artifacts to natural objects (body parts), and also provide preliminary evidence that this sense of complexity, although more variable, is present already at age five. Interestingly, children's ability to form and use abstract concepts dramatically increases from ages four to five onward. Even if this study does not focus on abstractness, it shows that children gradually develop the ability to rely on experts and that this reliance on others increases the more casually complex objects are.

More crucial to us is a study testing deference when learning abstract concepts, such as numerical ones. Kominsky et al. (2016) (see also Kominsky & Keil, 2014) investigate the processes that lead children aged five to six, older than nine and adults to rely on the competence of others. It is useful to select informants who are confident, but confidence might be a signal of ignorance when precise

information is unknowable. In the last case the admission of ignorance might not be “mere ignorance” but rather “virtuous ignorance”, the admission not to know something that is impossible to know. Children of first, second-third, and fourth-fifth grade were tested in a study of numerical knowledge on abstract concepts (e.g., it is possible to know the number of windows of the White House, but not the number of all the leaves of all the trees in the world), and children of second and fourth grade and adults were tested on specific vs. unknowable predictions about the future (e.g., it is possible to predict that a rainbow seen on October 1, 2224 will have a red stripe on top, but not that the most popular boy name on that date will be George). Children were asked questions and were invited to choose the best experts to help them to answer the questions. Kindergarteners and first graders tended to favor implausibly confident informants, whereas fourth graders and adults did not. In the experiment on future predictions, second graders tended to favor implausibly knowable informants, fourth graders were at chance, and later the performance significantly increased. Importantly, when asked to determine whether items were knowable and not, even four- to five-year-old children were able to do it, revealing sophisticated epistemological capabilities. However, they were not able to choose implausibly certain informants over virtuously ignorant ones. This might depend on the difficulty to integrate information on the words and on the experts, or on their difficulty in not believing what they are told. The ability to choose the right informants is particularly crucial for the acquisition of abstract concepts, for which knowledge that is not obvious is required.

Collective definition of meaning

So far we have seen that, when our confidence in word knowledge is scarce, we refer to experts. We have introduced the importance of deference—linguistic deference when it refers to meaning. Deference can be explicit when we directly ask information of others, or implicit when we simply absorb information from them.

Importantly, such deference is not automatic; in some cases we may prefer to stick to our own definition than to adopt the one of the community. In other cases, conceptual meaning can be defined collectively. Take for example religious concepts: we might want to rely

on authoritative sources, such as sacred books or priests. The same occurs for scientiﬁc concepts: we might rely on specialist journals, or on scientists. But if we are scientists, then we might try to build/deﬁne a notion in a collective way. Consider for example the deﬁnition of "abstract concepts". Some authors introduced it. Other authors reﬁned it. Some authors proposed to drop it because it is oversimpliﬁed. This negotiation process involves a metacognitive judgment, the evaluation of whether this notion is reliable or presents limitations (Shea, 2019). This process of collective deﬁnition always occurs (Baronchelli et al., 2010), but it is more pronounced for complex abstract concepts than for concrete ones because no external referent is present.

When we refer to experts we implicitly recognize that meaning is distributed across different heads. The single members of a community might not be aware of all the nuances of the meaning of single words. This is the so-called division of linguistic labor: "Every linguistic community ... possesses at least some terms whose associated 'criteria' are known only to a subset of the speakers who acquire the term, and whose use by the other speakers depends upon a structured cooperation between them and the speakers in the relevant subsets" (Putnam, 1975, pp. 145–146).

It is possible that children assume this division of linguistic labor more than adults. Children typically grant parents, teachers, etc., expertise on word meanings they do not have. As for adults, it is possible that in present times deference becomes increasingly more important as we rely more on the Internet and other outside sources in our everyday life. At the same time, for adults it is easier to unmask pretend experts. In a recent study, Kominski et al. (2014) revealed a very interesting Misplaced Meaning (MM) effect. The idea is that only a subset of speakers know the distinctive difference between pairs of words, while other people might overestimate their knowledge. They hypothesize that this overestimation is stronger in children. The effect is due to the fact that participants know the concept only at a coarse, more abstract level, but are convinced they also know it in its details. They selected word pairs that were synonyms (e.g., infant-baby), word pairs with well-known differences (e.g., donkey-mule), and word pairs without well-known differences (e.g., cucumber-zucchini). Both children (kindergartners, second, and fourth graders) and adults had a

clear MM effect: for example, they estimated that they would name three differences between cucumber and zucchini, but in a subsequent listing task they mentioned only one difference. The MM effect was more marked in kindergarteners, who gave higher estimates and provided fewer differences than older children and adults. The effect was present for distinctive aspects of word meaning, but not for common aspects, excluding the hypothesis that it is owing to broad metalinguistic overconfidence. It is possible that the stronger effect for kindergartners was due to the fact that because they were aware of the presence of experts, they felt more confident than older children and adults. Consistently, Koenig and Harris (2005) have shown that young children rely on knowledge coming from outside sources, and can use in a smart way these networks of deference. Indeed, knowing that we are part of a community in which there are some experts might increase confidence.

Hence, we rely more on others when we feel less confident. At the same time, the awareness that we can rely on others might induce in us a feeling of overconfidence (Rabb et al., 2019). This can happen especially with abstract concepts that we master less than concrete ones. Empirical research should investigate these two concurrent and contrasting phenomena.

Social Metacognition and Abstract Concepts in Use

Abstract concepts have mostly been studied as isolated items; Barsalou et al. (2018) have underlined that it is necessary to study concepts in situated action. In a similar vein, Glenberg (2019) and Falandays and Spivey (2019) argued that, because abstract concepts rely more on social interaction and because their meaning is more variable than that of concrete concepts, we should investigate their use in social interactions. We think that future research on abstractness will need to investigate concept use in real-time dynamic interactions. For example, superordinate concepts might generate more uncertainty when we comprehend them, but in the case of degraded perception we might feel more confident in using a superordinate than a lower level term. It is therefore crucial to investigate the real use of words in dialogue. Focusing on the use of abstract concepts will allow us to better detect the process of meaning search that follows the

monitoring processes, and the process of social deference that can be the outcome of the feeling of scarce con dence they generate in us.

Conclusion

Metacognition and social metacognition can play an important function for concepts in general, but especially for abstract ones. Here we have argued that metacognition can play multiple roles for abstract concepts. First, it contributes to their grounding. Second, the monitoring component of metacognition is particularly relevant for them: the higher the degree of abstractness of concepts, the longer the metacognitive process lasts, the less we experience con dence in their meaning and the more we continue searching for it. The monitoring process can lead to two possible outcomes. The rst is the use of inner speech, aimed for example to re-explain to ourselves the word meaning. The second is the stronger need for social deference, leading to a form of social metacognition. We need other people—better if they are authoritative—more the more gaps our knowledge has. We thus prepare ourselves to use language to request their help. Comprehension of abstract concepts leads us to prepare an action, but it generally is a linguistic action, most likely a request. Abstract concepts can thus be rede ned as concepts for which the mediation of others is crucial. The more concepts are abstract, the more we need to know. Why in some cases we use the rst mechanism, and in others the second, should be investigated by further research. One possibility is that we use the second system, social metacognition, when the simple inner search through inner speech fails. Another possibility is that both mechanisms are concurrently activated. Both in the cases in which we continue searching for the meaning and in which we request the help of others the mouth motor system is activated. In the rst case, the mouth might be activated because we use inner speech. In the second case, it might be activated because we prepare ourselves to ask questions of other people. Future research should deepen these aspects, adopting methods allowing us to capture use of concepts in real-time interactions.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_10

10. Phonemes Convey Embodied Emotion

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Abstract
We contrast the traditional view that vowel phonemes are neutral, abstract building blocks with an understanding that they convey activities of embodied emotional facial musculature. In theory, the same facial musculature associated with visually recognizable emotional expressions also favors the production of auditorily recognizable sounds. We found a relational commonality in the distribution of phonemes across perceptual, acoustic, and biomechanical metric spaces that maps well onto emotional dimensions of valence and arousal. Speci□ically, /i:/-sounds (like "Gleam") are associated with more positive emotional valence than /ʌ/-sounds (like "Glum"), and /æ/-sounds (like "Wham") are associated with more arousing emotions than /u:/-sounds (like "Womb). These trends generalize to other languages, across species, occur with both words and pseudo-words, and can be enhanced or inhibited by manipulating facial musculature. These types of acoustic associations complement and integrate with other forms of embodied sound symbolism such as onomatopoeic □indings related to bouba-kiki

phenomena, but the phoneme-emotion relationship is more robust and provides a stronger functional basis for understanding language development and evolution. The phoneme-emotion relationship provides a potential explanation for why humans originally evolved the ability to so finely discriminate the acoustic phonemic characteristics upon which language is scaffolded. In short, phonemes may initially have effectively served as general acoustic emotion-detection features.

Keywords Embodied cognition – Sound symbolism – Emotion – Language evolution

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The Scientific Ideal of Common, Neutral, Minimal Atomic Units

The uniqueness of human language is often characterized by our ability to assign different meanings to arbitrary sounds, with minimal phonetic utterances typically thought of as abstract, relatively neutral building blocks. This characterization promotes a long-standing type of scientific aesthetic ideal, with references to the general concept of common, neutral, minimal atomic units dating back as far as Mochus the Phoenician in the fourteenth century BC (Honderich, 2005). The first indisputable proponent of atomic theory is usually credited to Democritus (460–370 BC), who has been described as the "father of modern science" (Gossen, 2002). A contemporary of Socrates and Plato, Democritus, clarified the scientific aesthetic that if a phenomenon like matter can be broken down into its most basic neutral, minimal, atomic building blocks, then all relational principles can be scaffolded upon them. This type of modeling, based on the commonality of neutral minimal building blocks, has led to pioneering advances in many scientific disciplines including atomic units being the basis of the periodic table, photonic units being the basis of the physics of light, neural units being the basis of neuroscience, and phonemes being the basis of models of human speech production and perception. In the case of language theory, the neutrality of phonemes is often the fundamental argument made for the uniqueness of human speech such that, unlike vocal communication in any other species, we

create spoken languages with virtually unlimited freedom to assign any meaning to arbitrary series of neutral phonemic building blocks.

Today, language researchers largely agree that it is an oversimplification to try to reduce models of speech to entirely neutral, abstract units, yet this often remains an unsaid assumption for representations classifying phonemes, formants, and tongue and mouth biomechanics. For example, the ***International Phonetic Alphabet*** (***IPA***) specifically avoids descriptions of any type of meaning structure and describes pronunciation dimensions primarily with respect to tongue position and mouth mechanics. Past speech researchers have also had difficulty accurately specifying the acoustic characteristics of speech well enough to make viable speech-recognition systems based only on acoustical phonemic units. It is only over the past decade that reasonably reliable automated speech-recognition systems have become commercially available, and these are based largely on complex proprietary machine-learning algorithms that remain largely opaque to most speech scientists (Deng & Li, 2013). The historic lack of acoustic–phonetic invariance has led to speech unit classification systems based on non-acoustic features like tongue position and mouth shape that likely contributed to the dominance of speech-recognition models based on such production features. This has promoted a school of embodied speech-perception modeling with a type of sound symbolism that incorporates motor aspects of production behavior in order to accurately perceive speech. In the current chapter, we clarify and outline a complementary but different type of embodied sound symbolism that is based on associations between acoustic cues and basic emotions.

Embodied Cognition and Sound Symbolism in Language

Traditional language studies broke down language into various smaller and smaller units starting from context, syntax, lexeme, morpheme, and phoneme. This approach continues the assumption and common understanding that the relationship between phonemic units and meaning is abstract and arbitrary, an approach that dates back to de Saussure, who is often described as the father of linguistics. De

Saussure (1983) extended the idea of linguistic arbitrariness to a lack of connection between meaning and sounds of whole words or lexeme groups of words. The notable American linguist Charles Hockett (1960) also proposed this type of acoustic arbitrariness as one of the defining features that separates human language from animal communication.

The inability of traditional bottom-up acoustic models to account for how listeners are able to parse and understand phonemes helped give rise to embodied cognitive speech recognition models with cognitive processes that are based on perception, action, and emotion (Glenberg, 2010). This approach allows for cognitive associations with body states that can add a type of meaning valence to basic units like phonemes, in contrast to the traditional neutral, abstract, aesthetic ideal. The idea of basic sound units having embodied, non-neutral meaning associations has initially largely been supported by language theorists promoting the idea of sound symbolism.

Words like “zip”, “burp”, and “bark” all demonstrate sound symbolism, links between word pronunciation and meaning. Here, the words are onomatopoeic, words whose pronunciations mimic acoustic aspects of the named object. The Bouba-Kiki effect is one of the most well-known and best-documented sound symbolic effects (see Fig. 10.1). First described by Köhler (1929) and replicated by Ramachandran and Hubbard (2001), the Bouba-Kiki effect describes the tendency for participants to name rounded cloud shapes with words like “Bouba” and sharp spiked shapes with words like “Kiki”. Most research on this topic promotes sound symbolic explanations of the Bouba-Kiki effect, typically as an example of embodied multisensory onomatopoeic phenomena (Margiotoudi & Pulvermüller, 2020). It has also been replicated in other cultures and with young children (Fort et al., 2018; Maurer et al., 2006; Motamedi et al., 2020).

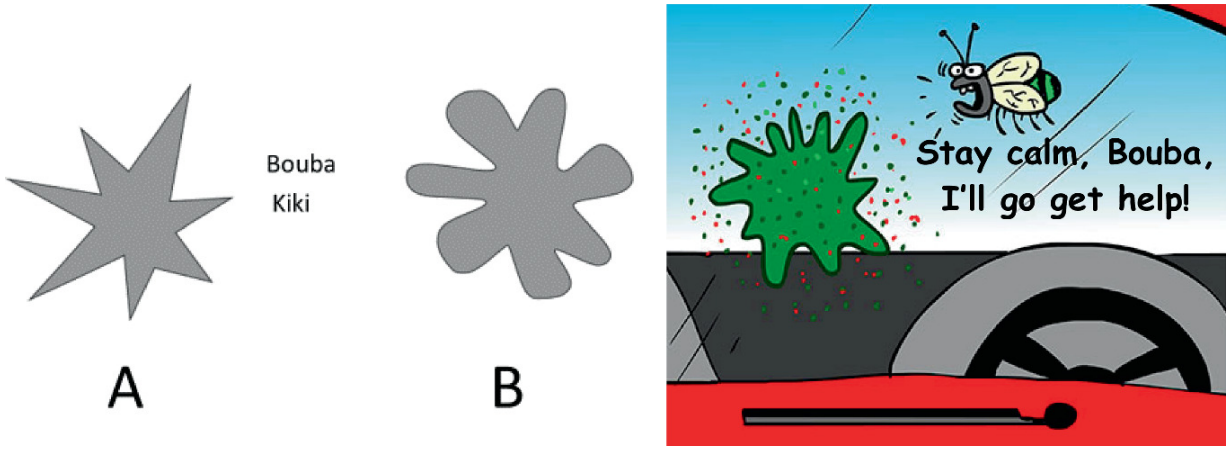


Fig. 10.1 Sound symbolism exempli𝔣ied by the Bouba-Kiki Effect. Here observers favor matching the word "Kiki" with sharp-pointed 𝔣igures like (a) and matching "Bouba" with rounded 𝔣igures like (b). This is typically described as an example of embodied multisensory sound symbolism in which bright, rapidly changing acoustical sounds of "kiki" and the more muted, elongated sounds of "bouba" have been found to have an onomatopoeic connection to corresponding shapes. The comic shows the original "Bouba" (credit goes to original artist).

We recently explored and extended these types of associative relationships using matched pairs of nonsense pseudo-words that differ only in the middle vowel (Barlow & Gierut, 2002). We tested two vowel sounds with extreme differences in timbre brightness, /i:/ (like "weem") and /ʌ/ (like "wum"). We found that pseudo-words containing /i:/ are more likely to be paired with random shapes that have distinct edges, move rapidly, and are brighter and more color saturated, while matched pseudo-words containing /ʌ/ are more likely to be paired with random shapes that have blurry edges, move slowly, and are dimmer and less saturated in color (McBeath et al., 2018). Another sound symbolic case links vowel sounds to object size. Sapir (1929) documented that participants were more likely to assign smaller objects names that contain close front vowels, like "mil", and assign larger objects names that contain open back vowels like "mal." In short, 𝔣indings with pseudo-words like "mil" and "mal" support the generality of onomatopoeic aspects of sound symbolism that are consistent with multisensory embodiment, but the theory as it applies to language in general remains somewhat vague without clear functionality.

These types of sound symbolic 𝔣indings demonstrate a type of embodied multisensory language processing in which phonemes are not arbitrary neutral sub-units of language. Research supports that

visual shape, motion speed, brightness, and color saturation can all be mapped in some manner onto acoustic dimensions of phonemes. Other work has shown that phonetic characteristics like formant distribution are related to emotional meaning, but that work does not specify a clear reason why this relationship should hold (Auracher et al., 2020). A more functional understanding of sound symbolism requires consideration of why phonemes evolved to be discriminated and categorized as they are, with some kind of functional basis. In the next section, we review the variety of models of vowel phoneme categorization and show how the principal phonemic dimensions in different models all converge to a common global relationship that also appears to be related to the sensing of aspects of emotion.

Modeling Vowel Phonemes

In the preface to the first edition of his 1863 auditory classic book, ***On Sensation of the Tone***, Hermann von Helmholz (1863/1954) made a specific point to express his gratitude to the Bavarian King Maximilian for his munificence in funding the critically important apparatus created to mechanically produce vowel sounds. In his book, Helmholtz defined the new field of acoustic psychophysics with the principal auditory dimensions of loudness (perceived intensity), pitch (perceived fundamental frequency), rhythm (perceived timing pattern), and timbre (perceived spectral pattern), and he had the insight to note that differences between vowel sounds are a fundamental aspect of timbre. He sought to determine the acoustic characteristics that make certain tones sound like vowels and to determine what makes vowel phonemes sound so dramatically different from each other, even when matched in loudness, pitch, and rhythm. By building an apparatus that could individually control the intensities of a series of harmonically related tuning forks, Helmholtz was able to demonstrate that the different vowel phoneme sounds can be artificially produced by simply increasing intensity within specific spectral ranges of overtones (i.e., energy bumps near specific harmonic frequencies). He called these frequency energy bumps ***Voweltönes,*** which we now refer to as ***Formants***.

Helmholtz (1863/1954) verified the roughly exponentially decreasing harmonic partial or overtone structure that is common among resonant animal calls and musical instrument tones, and he was the first to map out the relationship between individual vowel phoneme sounds and the acoustic frequencies of the first two formants. He referred to the effect of the time-averaged spectral envelope as tone ***color***. He also clarified a second major dimension of timbre, ***dissonance*** (or in German what he called ***Klangverwandtschaft)***, which he found to be a function of the degree of harmonic misalignment and acoustic beating between overtones. Today this dimension is usually referred to as ***Harmonicity*** or ***Tonality***, and physically can be defined as the extent of acoustic overtone-harmonic alignment, which also corresponds to the degree to which a sound is perceived as a clear tone with a distinct fundamental frequency. In the century and a half following Helmholtz's discoveries, the sustained spectral components of timbre have generally been characterized as having these two dimensions, ***Harmonicity*** and the sustained aspect of acoustic color now referred to as auditory ***Brightness*** (or ***Sharp-Dull*** or ***Tone Height***), which can physically be defined as roughly the spectral centroid (Patten et al., 2019). There are also several important temporal components of timbre corresponding to dynamic attack-decay patterns of the fundamental and relative partials (Grey, 1978), but the work investigated in the present chapter concentrates principally on the sustained spectral components, with the finer dynamic aspects reincorporated in the final discussion. Helmholtz's seminal findings clarified the specific acoustic properties associated with the major sustained aspects of timbre, and he was one of the first to recognize the foundational importance of vowel sounds as fundamental characteristics of timbre.

A compelling aspect of the formant characterization of vowel phonemes is that remarkably similar relationships between vowel-sounds emerge when plotted as a function of the following four metrics: (1) listener-rated auditory similarity, (2) the first two formant frequencies, (3) mouth muscle behavior, and (4) tongue placement. Figure 10.2 shows vowel similarity plots of these four types of metrics. Figure 10.2a shows an example of a two-dimensional multi-dimensional scaling solution based on pairwise similarity judgments of

the 12 monopthong North American English vowel phonemes (Patten & McBeath, 2020). Similar plots date back to the work of Du Bois-Raymond (1812) and a number of others who followed (Plomp, 1976; von Bismarck, 1974). Two well-defined dimensions, discussed above, consistently emerge, ***Harmonicity*** (overtone-harmonic alignment) spanning vowels /***æ***/ (as in "bat") to /***u:***/ (as in "boot") and ***Brightness*** (spectral centroid) spanning vowels /***i:***/ (as in "beat") to /***ʌ***/ (as in "butt"). The same vowel pattern emerges in each of the other three metrics shown in Fig. 10.2b–d.

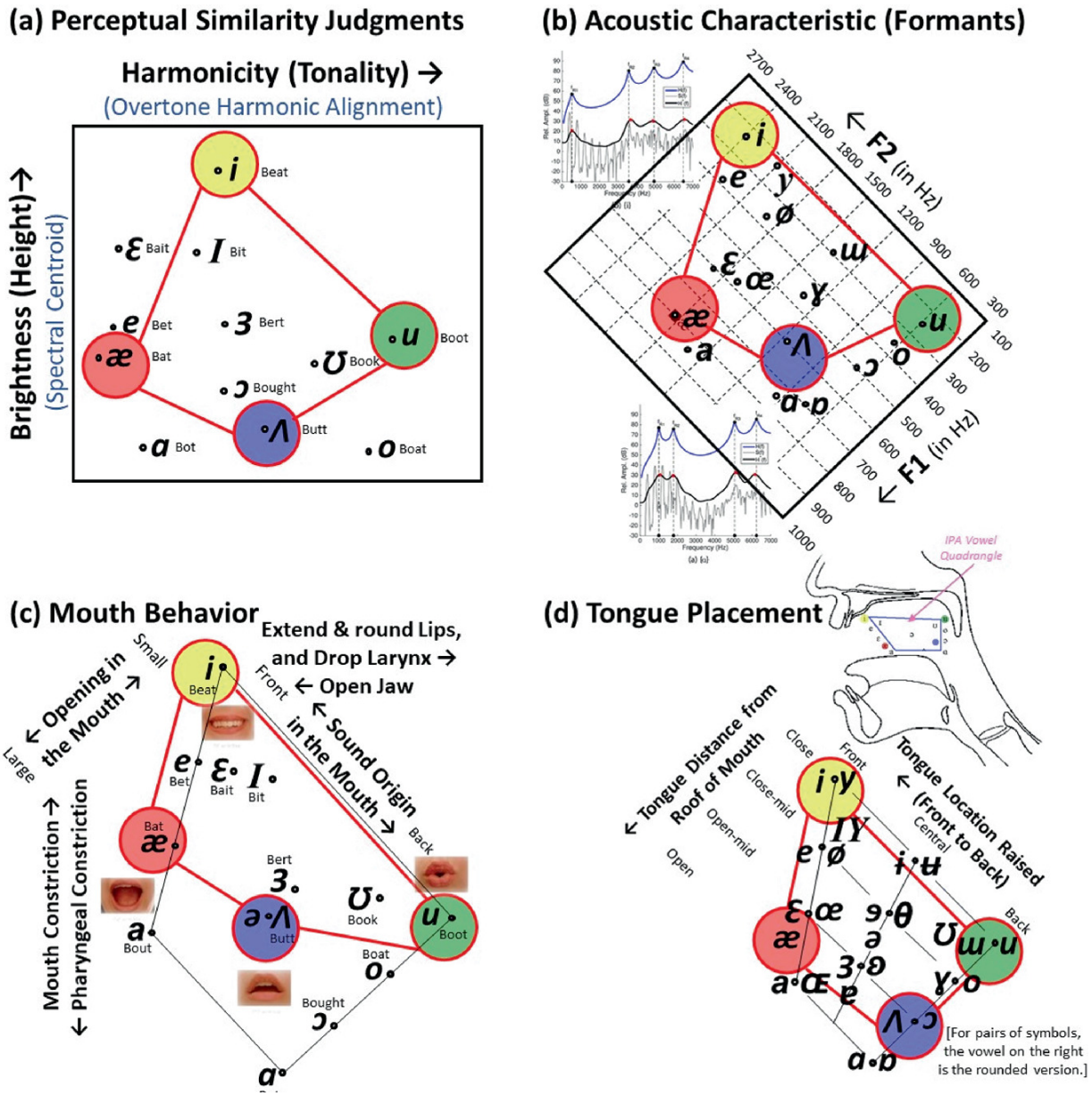


Fig. 10.2 Geometric representations of vowel phonemes based on four metrics of similarity. a Listener-rated similarity and emergent perceptual dimensions. The 2-D Multi-Dimensional Scaling solution for similarity of the twelve monopthong North American vowel phonemes. Two well-defined dimensions emerge. One, spanning vowels /æ/ to /u:/, significantly correlated with auditory Harmonicity, while the second, spanning vowels /i:/ to /ʌ/, significantly correlated with experienced Brightness (or tone height). b As a function of acoustic frequencies of the first two formants. c As a function of mouth and lip characteristics. d As a function of tongue placement for the International Phonetic Alphabet. Four extreme perceptually judged phonemes, /i:/, /ʌ/, /æ/, and /u:/, exhibit a similar divergent relationship in all four representations. Plots 1(b), (c), and (d) are rotated to align with the phoneme pattern in the 1(a)

Figure 10.3 replots these same four extreme vowels in a diagram that combines all four metrics. The only vowel of these four that may not appear to be an obvious extreme is /***ʌ***/, but it was chosen because perceptually /***ʌ***/ was consistently rated to have the lowest tone height and it is the phoneme most consistently produced when participants attempt to vocalize a low 60 Hz sine wave (Patten & McBeath, 2020). Additionally, /***u:***/ and /***æ***/ specify a nearly orthogonal dimension and are the two phonemes that respectively produce the most and least harmonicity as defined by harmonic overtone alignment (Patten et al., 2019). Thus, these four vowel sounds provided four roughly orthogonal acoustic extremes that very well exemplify the psychophysical dimensions of ***Brightness*** or ***Tone Height*** (Shepard, 1964) and ***Harmonicity*** or ***Tonality*** (Chan et al. 2019; Helmholtz, 1863/1954).

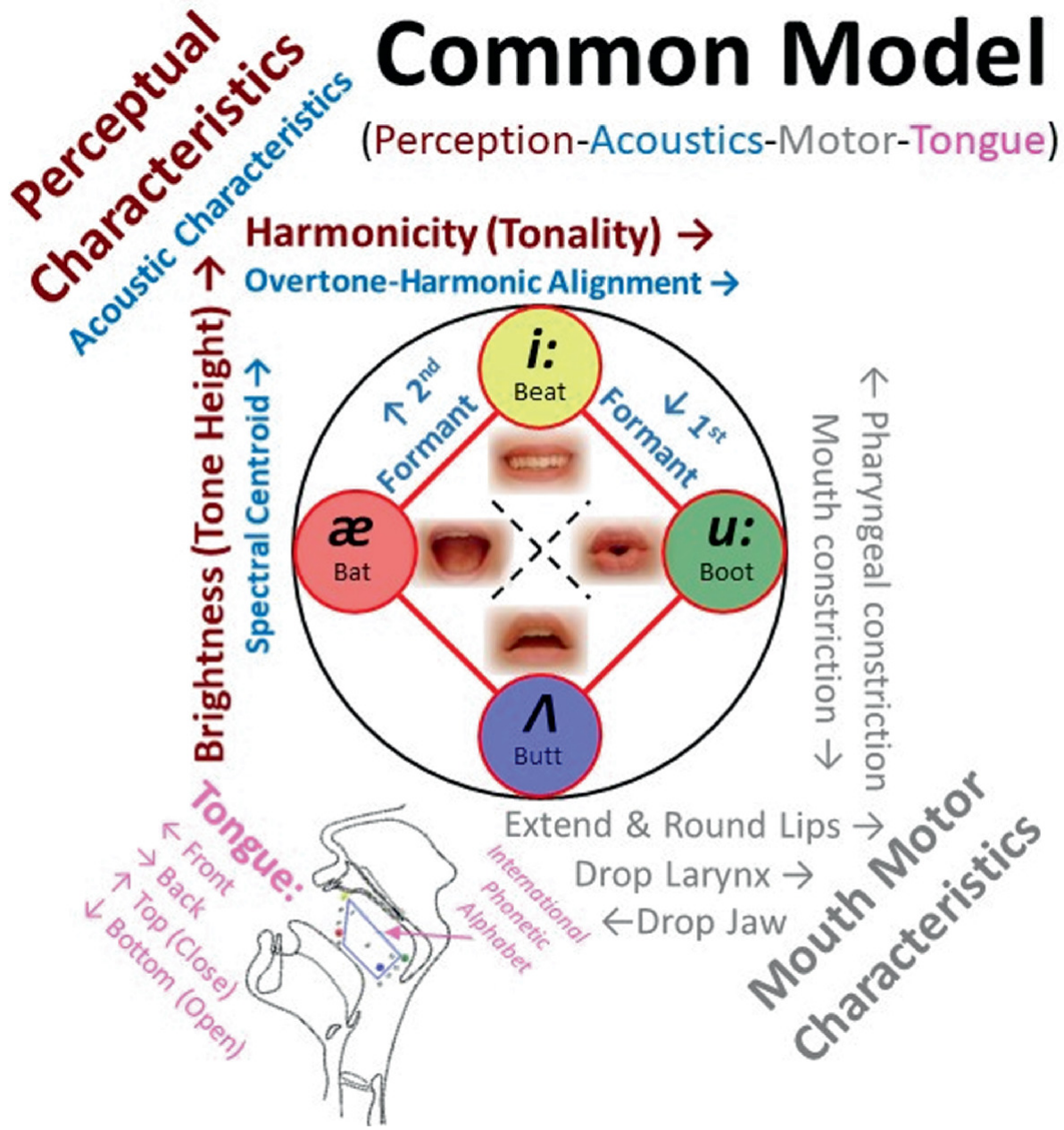


Fig. 10.3 Geometric Representation of Four Extreme Vowel Phonemes, Integrating Different Metrics. The figure combines into a single representation the similarity metrics of perceptual judgments, acoustic characteristics, motor characteristics, mouth and tongue position, and formant location

Helmholtz (1863/1954) and most acousticians following him have not elected to explore why humans evolved a predisposition to be so sensitive to the tone color distinctions between vowel phoneme sounds. Clearly, the capability to auditorily distinguish vowel sounds is foundational to the human ability to understand speech, but the

question remains as to why humans initially developed the predisposition to categorize along the particular perceptual dimensions upon which the fundamental processes of human speech scaffold. In the remainder of this chapter, we present findings supporting that these phonemic dimensions were naturally selected because they acoustically communicated muscle activity that is related to emotional expressions.

Modeling Emotions

Less than a decade after Helmholtz's (1863/1954) book was released, Charles Darwin (1872) published the ***Expression of Emotions in Man and Animals***, his third great book laying out his theories of evolution. Here Darwin wanted to simplify characterizations of emotion, which at the time were (and still are) often described in terms of dozens of categories. Darwin pointed out that human and animal emotions appear to show species-wide characteristic motor behaviors that are typically easily recognized by others, for which he suggested six basic emotional categories: happiness, sadness, anger, fear, disgust, and surprise. Darwin speculated that emotional expressions and the ability to recognize them had survival value and were therefore evolutionarily selected. In the century and a half following Darwin's book, a number of prominent psychological theorists proposed refinements to Darwin's idea of a direct relationship between emotions and motor behavior (Cannon, 1987; James, 1884; Lange, 1885; Lazarus, 1984; Schachter & Singer, 1962), and more recently, Ekman (1992; Keltner et al., 2003) and his followers have carried the mantle. Yet, despite some differences, essentially all these models maintain Darwin's notion that there is a general embodied relationship between musculature, particularly facial musculature, and both expressions and recognition of expressions of emotion and that these are generally culturally universal (Cohen & Keltner, 2020).

There has always been controversy regarding Darwin's and Ekman's basic emotions, and that continues today. One point is the idea that there might be a better set of emotional categories specific to humans, both with more positive emotions (such as awe, pride, and serenity) and the concern that some of the original emotions do not

seem to be particularly easy to detect and discriminate (e.g., differences between fear, disgust, and anger). A second criticism is that people often learn to mask their facial expressions while still feeling strong emotions, so a tightly coupled facial feedback hypothesis appears to not universally hold.

A popular alternative model of emotions that does not require as tight coupling between facial expressions and specific emotions is Russell's (1980) Circumplex model. As shown in Fig. 10.4, this model classifies extreme emotions with the dimensions of ***Valence*** (Positive versus Negative) and ***Arousal*** (versus Calmness), and more recently, a third dimension is included, ***Dominance*** (versus Submissiveness). This model has the potential weaknesses of being overly simplistic and forcing complex emotions to fit into a geometrically expressible continuum, but it has been found to be reliable for the most recognizable extreme emotional states. In addition, if only the four principal emotions that correspond to the extreme corners of the two circumplex axes are included, then both the Darwin/Ekman model and Russell's circumplex model can be integrated to include something like (+Valence, + Arousal) = Joy. (−Valence, + Arousal) = Anger/Fear. (+Valence, −Arousal) = Serenity. (−Valence, −Arousal) = Dejection, which are common cornerstones in emotional modeling. Certainly, this is a limited set of emotions, but it was a goal of Darwin and his followers to clarify a small set of archetypical emotions, which are more universally displayed and recognized by humans and other higher mammals. This representation of emotions is of interest here, because, like the vowel representation noted above, it can be and has been described in terms of the musculature associated with the extreme states. We will next review evidence that there is a commonality between vowel space and emotion representations, presumably due to their common basic musculature states.

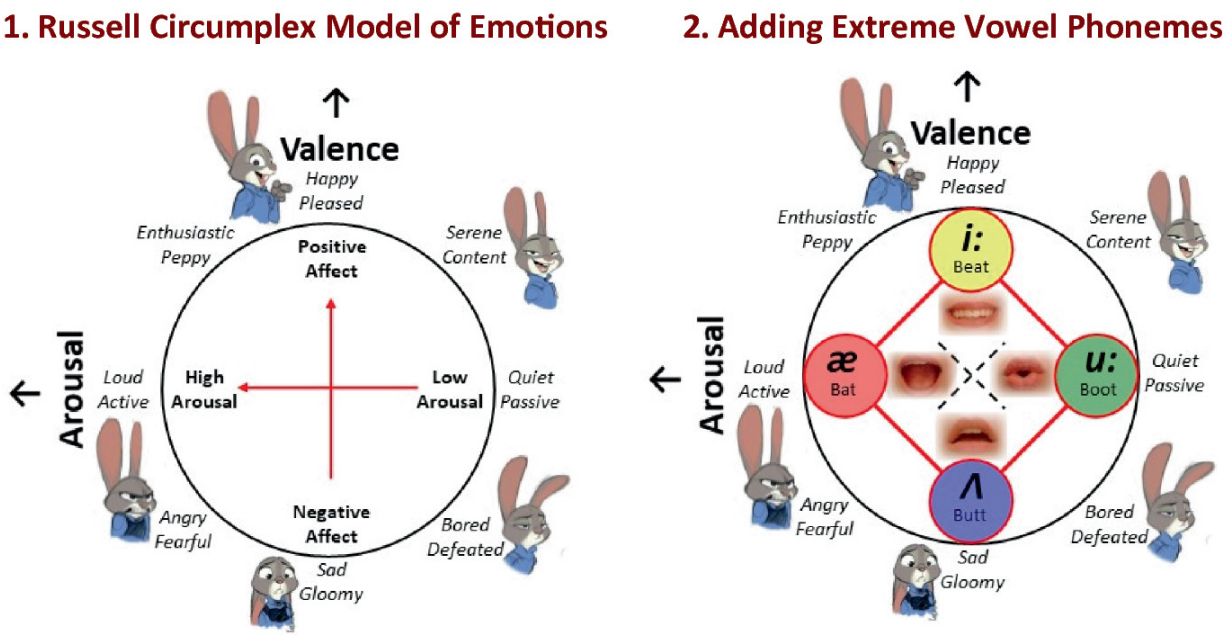


Fig. 10.4 The Russell Circumplex Model of Emotions. a The two principal dimensions are Valence (positive versus negative) and Arousal (versus calmness). The model was originally validated only for extreme emotions. The third dimension of Dominance (or Accommodation) that is not shown allows an additional distinction between emotions like Anger and Fear. Most of Darwin and Ekman's archetypal emotions can be included in this kind of simpli□ied representation. b The extreme vowel phonemes from the common similarity metric shown in Fig. 10.2 can be □itted onto this emotional model in a manner that appears consistent with the musculature of emotional expression. Included in the middle are the classic mouth expressions used to pronounce the extreme phonemes, which appear similar to those used to express the archetypal emotions

In summary, the categorization of acoustic sounds based on musculature that has been mapped out by acousticians and speech scientists appears likely to be related to the categorization of emotions based on musculature mapped out by emotion researchers, and this commonality might account for aspects of the development and evolution of language as an early auditory method of acoustically discerning emotional states. Our □indings support that the extreme phonemes of /i:/ versus /ʌ/ and /æ/ versus /u:/ (the dimensions that emerge from the MDS, formant, and musculature mappings of vowel phoneme similarity shown in Figs. 10.2 and 10.3) also map out onto the valence versus arousal emotional dimensions (the mapping shown in Fig. 10.4) due to their common underlying musculature.

Mapping Emotions with Vowel Phonemes

Resisting the ideal of atomic neutrality in modeling phoneme perception and accepting an embodied approach allow us to explore potential functionality underlying phonemic similarity dimensions. If listeners are able to glean information regarding facial musculature from sound, theoretically they could use sound to discern emotion. Emotion communication relies on the perception of motor behaviors. Experiencing emotions triggers motor behaviors that are also observable physiological byproducts. These typically involve the central, somatic, and autonomic nervous systems, presumably triggered due to survival demands. Vocal expressions that are precursors to human language are controlled by a limbic network and convey the producer's motivational states. Although the human brain evolved additional pathways that allow for more ﬁne-tuned control of voicing and articulation, the evolutionary more ancient system of vocal production shared by primates including humans is tied to affective states (Fischer, 2021).

Humans are one of a small subset of species who have evolved extensive auditory mimicry that also can be used as a tool to ﬁnely control auditory utterances. As noted earlier, past speech-recognition models have tended to emphasize aspects of how speech is produced, along with the resultant acoustic characteristics. The principal initial embodied perception idea has been that listeners distinguish phonemes in part by internally mimicking how they would produce the same sounds (Margiotoudi & Pulvermüller, 2020; Schomers et al., 2014). This approach supports that listeners could also consider their own musculature states in a manner that allows them to include emotional associations related to speciﬁc sound features. The advantage of a model based on sensing acoustic features that are related to emotions is that this provides a functional rationale for why we evolved a sensitivity to the particular dimensions that emerged in our common phoneme model. Given that phonemes appear to be related to facial musculature as shown in the common model, this supports the idea that the same underlying emotions that produce visually recognizable emotions also could favor the production of auditorily recognizable emotions. In short, phonemic discrimination may have originated from a means of gleaning the emotional state of vocalizers, and this ability to ﬁnely distinguish these acoustic features

later provided humans with the perceptual mechanisms and auditory skills to develop complex speech and speech perception.

Auditorily recognizable emotion cues can result from changes in facial musculature activity just as they can result from any other physiological changes. Findings from multiple studies support the idea that facial musculature activations triggered by emotions lead to auditorily recognizable emotion cues. Findings confirm that acoustic emotional cues produced by speakers are primarily due to manipulation of their facial musculature and not some type of disembodied interjection of emotions in their speech. One finding relating external facial muscle changes to acoustic effects showed that experimentally inducing smiles in speakers can lead to pronounced and reliable increases in the frequencies of the second and third formants (F2 and F3) (Tartter, 1980). This finding was later replicated by Arias et al. (2018) through a better-controlled stimulus set. Arias and colleagues first used machine learning to model acoustic changes in the spectral envelope, with speakers vocalizing both with and without a smile. They then created a new acoustic stimulus set by transforming the spectral envelope of the sentences spoken without a smile to reflect the acoustic features from their algorithm that were associated with smiling, while leaving other characteristics of the voice unchanged. They confirmed that listeners accurately rated the speakers as expressing more joy. Similar to this finding, other research has shown that when listeners have to guess whether speakers had a neutral or frowning facial expression while they were speaking, they accurately identified frowned speech (Tartter & Braun, 1994).

Our model, that there is a convergence of speech and emotional expression in facial musculature, is also consistent with brain model research. Specifically, neuroimaging studies and lesion case studies have led to proposals with structural and functional support that the insula is an area that maps emotions with vowel phonemes (Ardila, 1999; Uddin et al., 2017).

Together, the converging evidence across studies strongly supports that emotions can be recognized through acoustic features, with phonemes being promising contenders. In the next section, we provide empirical evidence supporting how emotions are mapped onto specific vowel phonemes. Figure 10.4b illustrates a simplified version of the

theoretical mapping. At the end of the empirical section, we conclude with a diagram showing the full phoneme-emotion model that includes all of the combined metrics.

Empirical Findings Supporting the Gleam-Glum Effect

We completed a series of studies that provides strong evidence supporting our proposed phonemic-emotion mapping, with most of the experiments utilizing a common methodology as follows. Participants are presented with a minimal pair of matched single-syllable words that contain the same beginning and ending consonant phonemes and only differ in the middle vowel phoneme (Barlow & Gierut, 2002). The task is to rate which of the two matched words exempli fies more of a particular emotional characteristic (either which is more positive, more negative, more rousing, or calmer). The comparisons are always between matched word-pairs containing either /i:/ versus /ʌ/ (e.g., ***Gleam*** versus ***Glum***) or /æ/ versus /u:/ (e.g., ***Wham*** versus ***Womb***). It is important to note that in order to make sure that word-pair stimuli were not cherry-picked to favor our hypotheses, an effort was made to include every single-syllable word in English (using the English lexicon project developed by Balota et al. 2007) and Chinese (using all possible pinyin combinations) that had matching /i:/ and /ʌ/ middle vowels or every single-syllable word-pair that had matching /æ/ and /u:/ middle vowels. By making the comparison between matched word-pairs, presumably the common beginning and ending phonemes should largely cancel out and eliminate any contribution due to those consonants.

Our experiments reveal a strong association between the vertical /i:/ versus /ʌ/ dimension in vowel space and the positive versus negative emotional valence dimension. In the first study of this type (Yu et al., 2021), we confirmed that /i:/-words (as in “Gleam”) were judged to be significantly more positive than matched /ʌ/-words (as in “Glum”), (***d*** = 1.03). We also replicated this finding in a test of Chinese Mandarin Pinyin, again using every possible combination of single-syllable word-pairs with middle syllables /i:/ versus /ʌ/, excluding neutral tone (Yu et al., 2021). A comparison of the two languages

produced no statistical mean or interaction differences, with both languages resulting in close to 2/3 of all single-syllable matched word-pairs of this type being rated in the direction consistent with the ***Gleam-Glum effect***. Figure 10.5 shows the mean valence rating difference for sets of matched word-pairs in English and Mandarin.

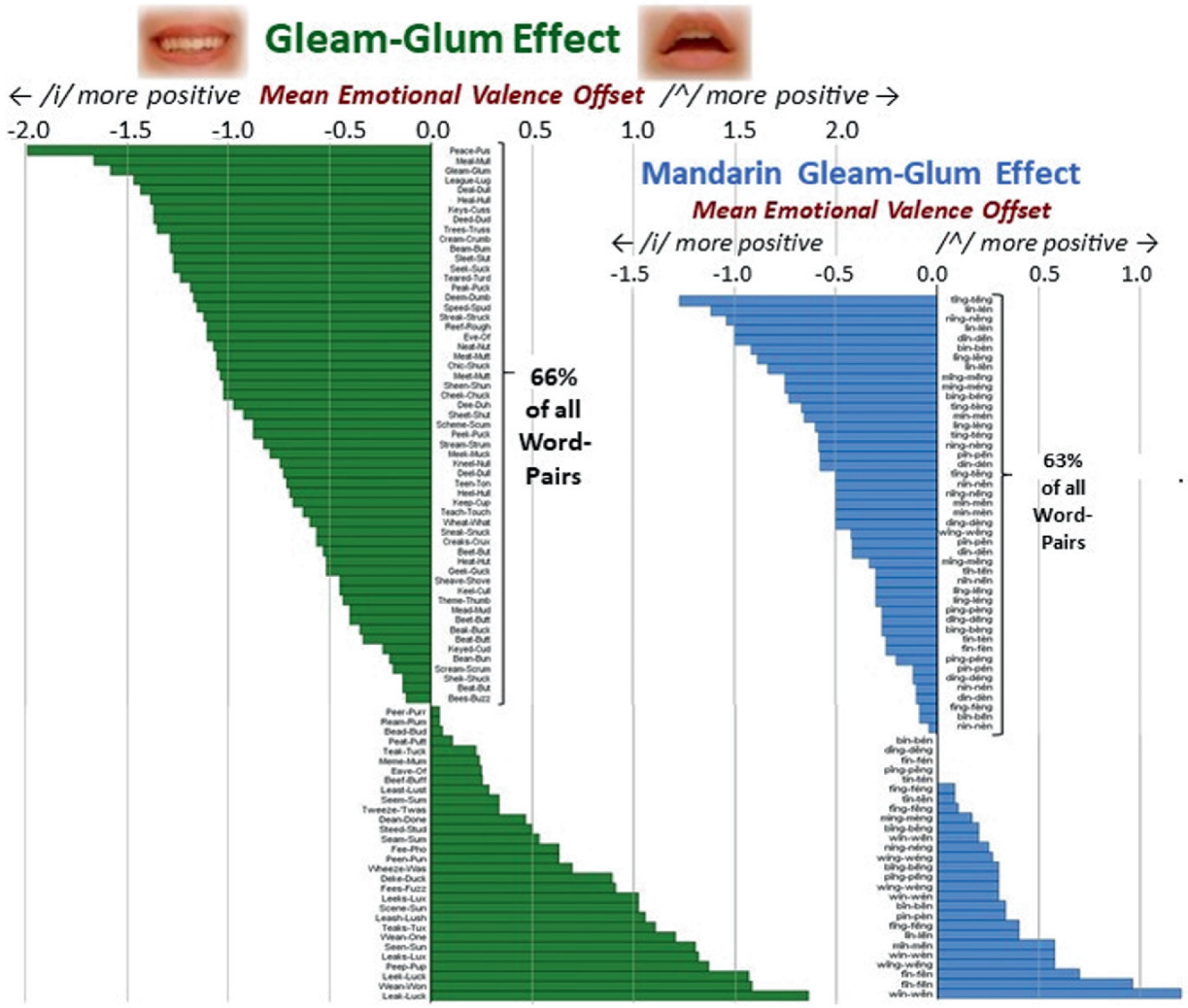


Fig. 10.5 Raw data results from Yu et al. (2021) study illustrating that nearly 2/3 of all single syllable matched word-pairs that contain /i:/ and /ʌ/ have the /i:/-word rated more emotionally positively in both English and Mandarin Pinyin. This finding supports that the ***Gleam-Glum effect*** generalizes across these characteristically different languages, with English and Mandarin also representing the two most populous languages in the world. The mouth configurations shown at the top illustrate the musculature used to produce /i:/ and /ʌ/ sounds, but also appear similar to happy and upset expressions

We also replicated the ***Gleam-Glum effect*** by comparing the valence rating between all English words containing the syllables /i:/ and /ʌ/

using the data set collected by Warriner et al. (2013). This finding confirms that the effect applies to the entire lexicon of English words (Yu et al., 2021). We further found evidence that the ***Gleam-Glum effect*** is moderated by facial musculature in a manner consistent with an embodied interaction. Specifically, we had participants rate the valence difference between matched pairs of single-syllable /i:/-versus /Λ/-words across three conditions designed to enhance, control, or inhibit their facial musculature response. Respectively, participants either read the words aloud (enhance), read silently (control), or read silently while chewing gum (inhibit). We found a significant linear trend with the largest ***Gleam-Glum effect*** in the enhance condition and smallest in the inhibit condition, and this trend is generalized across both English and Mandarin Pinyin. The full language and musculature moderation effects are summarized in Fig. 10.6. The findings confirm that the ***Gleam-Glum effect*** generalizes across both languages and facial musculature moderating conditions (Yu et al., 2021).

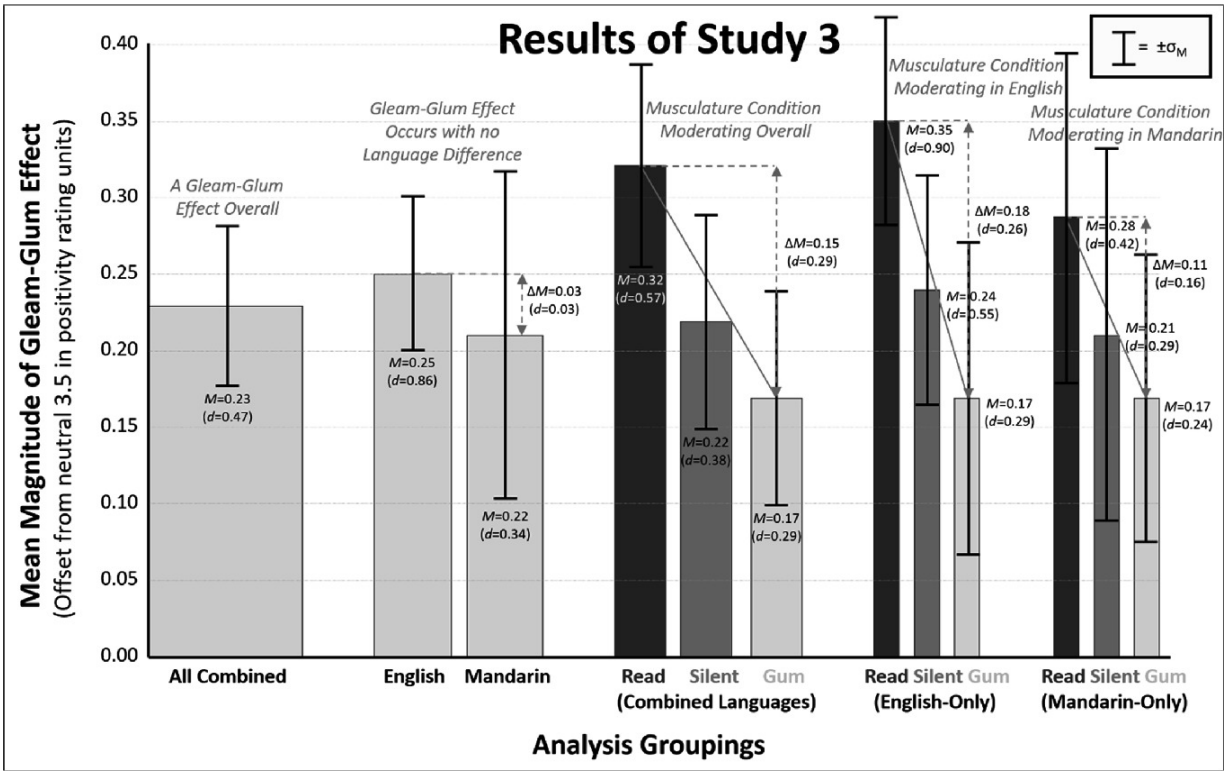


Fig. 10.6 Results of Yu et al. (2021) study confirming that the ***Gleam-Glum effect*** occurs in both English and Mandarin Pinyin and that it is moderated in both languages by facial musculature manipulation. Shown are the Cohen's d effect size magnitudes of the effect with bars grouped by variable, and the width of each bar representing relative sample size. Listed on or next to each bar

are the average relative valence rating between /i:/ and /Λ/ word-pairs and the corresponding effect size. Here positive valence values indicate the /i:/-word was rated as more emotionally positive. The first bar on the left illustrates the robust overall ***Gleam-Gum effect***, with /i:/ words reliably rated as more positive than matching /Λ/ ones. The second two bars show that the effect occurs to a similar, non-significantly different degree in both English and Mandarin Pinyin. The next triad of bars illustrates the results of the facial musculature manipulation, with a significant linear trend in which the effect was largest in an Enhance (Read aloud) condition and smallest in an Inhibit (Gum chewing) condition. The final two triads show that the musculature trend occurs similarly in both English and in Mandarin, supported by the lack of a significant interaction between the two trend slopes. The pattern of findings both confirms the generalizability of the gleam-glum effect across conditions and supports that the moderating effect of facial musculature occurs similarly in both English and Mandarin Pinyin

The ***Gleam-Glum effect*** sizes in English also appeared to be marginally larger for bilingual non-native English speakers, which is consistent with the effect increasing with the reduction of semantic salience of words (Yu et al., 2021). This was followed by a study in which we compared matched pairs of single-syllable nonsense pseudo-words with middle phonemes of /i:/ versus /Λ/, which produced an extremely large ***Gleam-Glum effect*** size of ***d*** = 6.92. The increase may have been in part enhanced by a new matching procedure that counterbalanced word-pairs against multiple positive and negative matching stimuli, but the end result confirms that under proper testing conditions, the ***Gleam-Glum effect*** is one of the strongest effects of sound symbolism to be empirically confirmed (Yu et al., 2020).

We also tested the extent to which the ***Gleam-Glum effect*** generalizes across the entire brightness (tone height) continuum of vowel space (the vertical dimension shown in Fig. 10.2a), (McBeath et al., 2019). We used the same procedure of rating matched word-pair valence differences with single-syllable words containing middle vowel sounds of /i:/, /I/, /Ɔ/ and /Λ/ (e.g., “deal”, “dill”, “doll”, and “dull”). Figure 10.7 illustrates the average effect sizes of all pairwise comparisons. We confirmed that the middle phonemes /I/ and /Ɔ/ do not significantly differ and cluster together and that the words in this middle cluster are rated as less positive than /i:/-words and more positive than /Λ/-words. Thus, they support a weak continuum that middle phonemes are generally associated with words that are middling in emotional valence, but do not follow a strong ordinal pattern. This is consistent with the full array of emotions that correspond to facial musculature patterns being somewhat complex.

They do not simply cleanly fall along only one or two dimensions like valence and arousal. Yet the result also conﬁrms that a weak such ordering does appear to be maintained and that the vowel sounds /i:/ and /Λ/ replicate as sounds associated with emotional valence extremes.

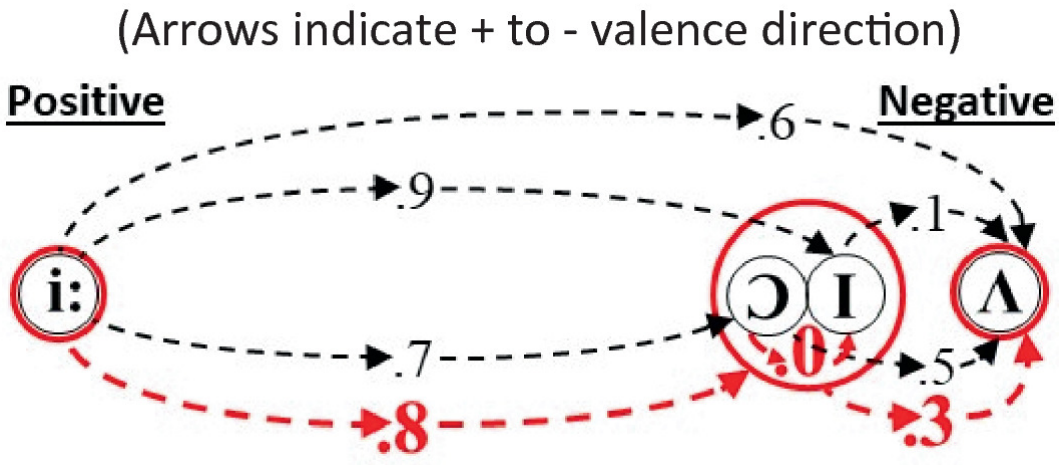


Fig. 10.7 Results reported in McBeath et al., (2019) showing the ***Gleam-Glum effect*** across the brightness vowel phoneme dimension, oriented horizontally. This diagram illustrates the effect sizes of ratings comparing the emotional valence of all single-syllable word-pairs containing the middle phoneme /i:/, /I/, /ɔ/, or /Λ/ (e.g., “deal”, “dill”, “doll”, and “dull”). Shown is a multi-dimensional scaling and cluster analysis model ﬁt in which horizontal distance from left to right represents positive to negative valence rating magnitude. As can be seen, /i:/-words are rated as most positive, /I/-and /ɔ/-words cluster together as a group rated in the middle, and the /Λ/-words are rated as the most negative. The pattern supports a weak ordering of vowel brightness (tone height) generally representing emotional valence

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Empirical Findings Supporting the Wham-Womb Effect

Similar to ﬁndings with the ***Gleam-Glum effect***, there is also signiﬁcant empirical evidence supporting that the /æ/ versus /u:/ horizontal acoustic dimension maps to the rousing versus calming emotional dimension. We found that participants rated /æ/-words as more rousing (or less calming) than /u:/-words (***d*** = 0.76) (McBeath et al., 2019). The ***Wham-Womb effect*** was conﬁrmed to be robust across instructional manipulation (whether participants rated relative arousal or calmness), with responses occurring in the predicted

direction for 75% of the word-pairs, exhibiting a reliable median effect size.

Given that the /æ/ versus /u:/ axis in the previously shown full model vowel space is roughly orthogonal to the /i:/ versus /Λ/ axis (that was found to reliably match up with emotional valence), the combined results support that the vowel space dimensions reliably match up with the orthogonal emotional dimensions of the Russell circumplex model, arousal, and valence. The orthogonality and some level of independence were supported when a control survey testing whether matched /æ/ and /u:/ word-pairs exhibit an emotional ***valence*** yielded no bias (***d*** = -0.01), (McBeath et al., 2019). Nonetheless, as indicated in Fig. 10.8, the /***i:***/ versus /Λ/ placement ended up being horizontally somewhat offset due to another test indicating /i:/-sounds are somewhat more rousing than /Λ/-sounds (***d*** = 0.87) (McBeath et al., 2019).

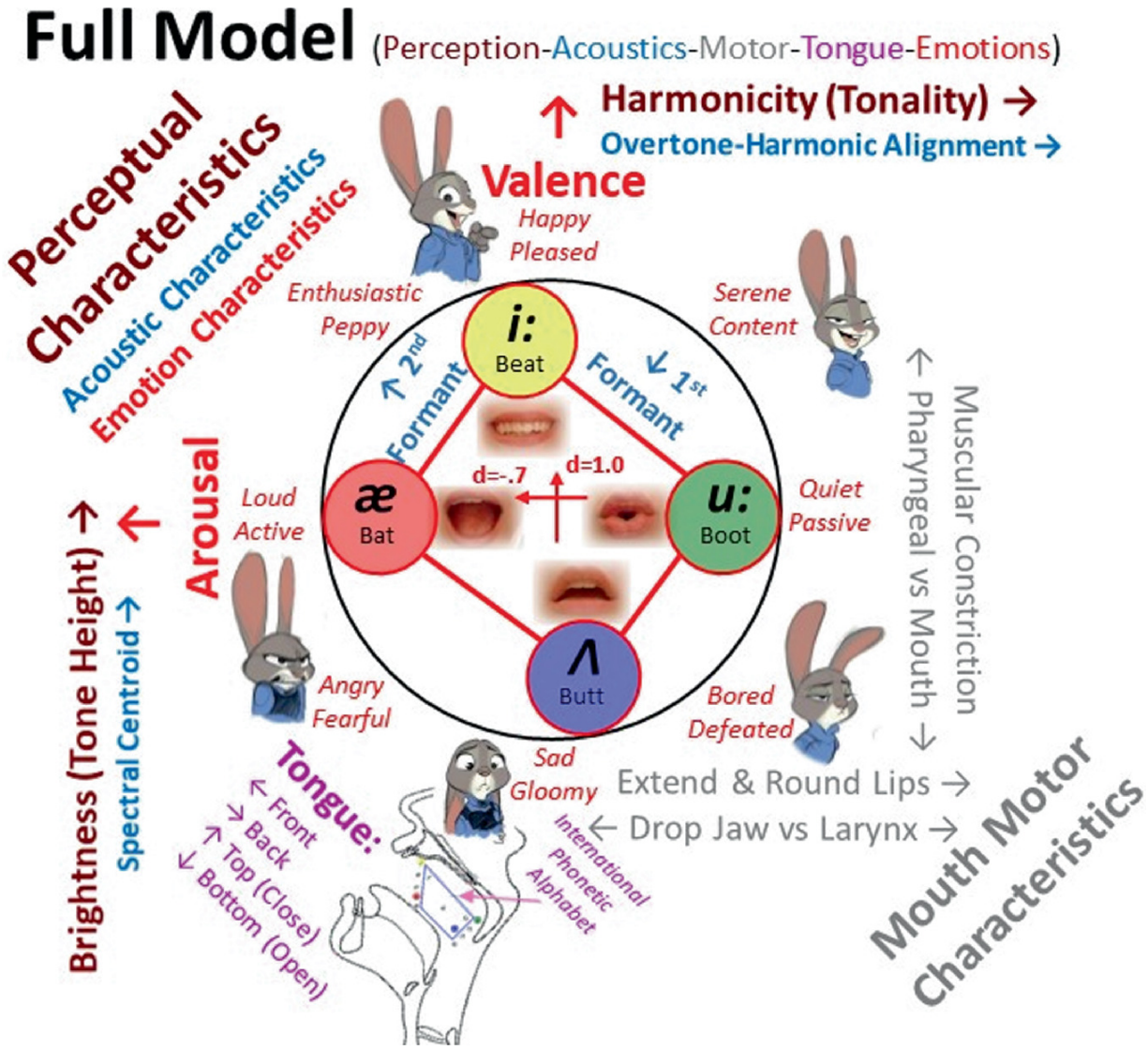


Fig. 10.8 General Geometric Representation of Four Extreme Vowel Phonemes, Integrating Emotions. The figure combines into a single representation the similarity metrics of perceptual judgments, acoustic characteristics, motor characteristics, mouth and tongue position, and formant location, along with the circumplex emotional dimensions of valence and arousal. Our suggested underlying basis is that the same facial musculature characteristics that typically produce visually recognizable emotional expressions also tend to produce auditorily recognizable acoustic patterns. Note the commonality between the standard mouth positions used to produce the extreme vowel phonemes and the emotional expressions to which they stereotypically correspond. Here the ***Gleam-Glum*** (/i:/ versus /Λ/) vertical dimension principally communicates emotional valence, while the ***Wham-Womb*** (/æ/ versus /u:/) horizontal dimension principally communicates emotional arousal, but the /i:/ versus /Λ/ are also somewhat offset horizontally given our finding that these also communicate some difference in arousal, with /i:/-sounds being somewhat more rousing

An Embodied Cognition Model of Language Evolution

Figure 10.8 shows a full model of the four extreme phonemes that we tested and how they relate to every metric that we previously discussed, all combined into one busy diagram. These mappings tie together perceptual, acoustic, tongue position, mouth motor behavior, and emotional dimensions via the four extreme vowel phonemes. The full model implies a common underlying causality that could in principle be due to any of these metrics, but logically is most likely a convergence due to repercussions of the facial musculature associated with emotions. In other words, all of the metrics converge to the same geometric representation because they all describe measurable physical aspects related to a person experiencing extremes of emotional valence and arousal that reflect the same underlying emotion-related facial musculature. This results in commonly related, nearly orthogonal dimensions that correspond to the phonemes /i:/ (as in "gleam") versus /ʌ/ (as in "glum") and /æ/ (as in "wham") versus /u:/ (as in "womb"), but likely also are related in various ways to other phonemes that have not yet been tested.

The underlying pattern is consistent with having the same facial musculature that typically produces visually recognizable emotional expressions also tend to produce auditorily recognizable acoustic patterns. This correspondence is expressed through having the same standard mouth positions used to produce the extreme vowel phonemes overlapping with the stereotypical emotional expressions. Here the ***Gleam-Glum (***/i:/ versus /ʌ/) vertical dimension principally communicates emotional valence, and the ***Wham-Womb*** (/æ/ versus /u:/) horizontal dimension principally communicates emotional arousal, but the /i:/ versus /ʌ/ phonemes are also somewhat offset horizontally, given our finding that they also communicate some difference in arousal, with /i:/-sounds being more rousing.

In contrast to the traditional neutral phoneme framework, the embodied emotional one can tie together musculature, acoustics, and perceptual similarity through a non-arbitrary relationship with emotions. The traditional framework is especially challenged given our

finding that the phoneme-emotion relationship is cross-linguistic (i.e., applies also to Mandarin according to our findings) and appears even stronger when extended to nonsense pseudo-words. The notion that language evolution has likely been affected by ties between musculature, emotions, and phonemic articulation is further supported by our finding that the ***Gleam-Glum effect*** encompasses the entire English lexicon and is increased or decreased by respectively enhancing or inhibiting the facial musculature through the moderating behaviors of saying words out loud and reading words silently while chewing gum (Yu et al., 2021). In short, the embodied emotional framework ties together the two types of language and speech evolution: both the origin and natural selection over time (Fitch, 2010). The origin addresses how human language and speech initially came to be, while the selection over time addresses the factors and manner in which language grows, survives, develops, and changes. The framework is based on the notion that the effective vocal production system that is the precursor of human language also continues to shape spoken language by way of word survival advantage. As the focus of our argument, emotional sound symbolic words whose definitions are in congruence with the mapping of emotions onto vowel phonemes (such as “gleam” and “glum”) are easier to learn and use, so they have more word survival advantage. In short, these words are more likely to persist in a spoken language over time while usage of words that do not reflect the natural mapping will tend to diminish (Adelman et al., 2018).

Several other findings also support the universality of specific sound symbolic factors that influenced language evolution of general acoustic features common across distinctly different languages. For example, Adelman et al. (2018) tested sound symbolism based on the phonemes of words across five different languages and specifically looked at the effect of the phonemes at the beginning of words. They found that phonemes significantly affected emotional valence, or “positiveness.” They demonstrated sound symbolism for both positive and negative emotional states due to front-loading the meaning by the predictive properties of the first phonemes of words. The study also found that the sound symbolism occurred at the level of individual phonemes rather than general phonetic features.

If a common mechanism evolved that ties emotional musculature to sound production, we would expect this relationship to also occur to some extent in other species. Findings in animal research further support such physiological influences on language evolution (Fitch, 2010). For example, Hauser and Ybarra (1994) tested the relationship between lip formations and vocal calls in the communication of Rhesus monkeys, which revealed interesting information regarding formants. In one subset of subjects, the lips of the rhesus monkeys were numbed with xylocaine to reduce the use of facial musculature in producing specific calls. They found that lip numbing significantly affected the first two formant frequencies of the monkey's calls without altering call duration or characteristics in the fundamental frequencies of the calls. Moreover, lip numbing had no significant effect on the "noisy screams" distress calls of the monkeys. The coos, however, were significantly affected. Unlike the noisy screams, the monkeys could not compensate for the lack of lip utilization in their cooing, resulting in coos with the first and second formants significantly raised. The inability of the lips to represent the motor movement of the monkey's faces failed to accurately replicate their emotional responses to situations, directly representing the importance of specific facial musculature in vocal emotional responses. Finally, it is interesting that the cooing of the monkeys was much calmer and exhibited more harmonicity, and the distressed screams were more arousing and exhibited less harmonicity, a pattern that parallels the acoustic-arousal relationship found in humans. Some of the commonality between human and animal vocalization patterns also appears to be due to common physics constraints (Scharine & McBeath, 2019). Humans and animal vocalizations, as well as musical instruments, exhibit the same patterns of correlations between changes in fundamental frequency and intensity, so when excited or muted, it is a common interspecies pattern to simultaneously raise and lower the vocalization in both of these acoustic dimensions together (McBeath et al., 2014).

The overall pattern of findings is consistent with early hominoids first being able to discriminate and recognize extreme emotional vocalizations in part by phonetic differences and then being able to use their ability to produce and perceptually discriminate phonemes to gradually expand into more metaphorical and abstract language. This

would help answer the earlier question of why humans are so sensitive to timbre changes dependent on formant patterns—the formants originally served as a cue to the emotional state of the person vocalizing, such that humans developed brain regions specialized to discriminate emotion-based acoustic cues that were later scaffolded into language centers. The standard auditory timbre dimensions of ***harmonicity*** and ***brightness*** can also generally be used to discriminate emotional valence and arousal, but given their correlations with formant frequency patterns in human speech, it appears that a quick assessment of emotions may have been ascertained by the formants alone (Ainsworth, 1976). In short, our findings are consistent with the notion that for early hominoids, formants could be used to quickly assess the valence and arousal states of vocalizers, which led to the development of brain areas specialized in sensing formants that now serve as language centers.

Auditory Analog to Darwin/Ekman's Universal Visually Recognized Emotionss

As discussed in the section describing emotion modeling, physiological changes and motor behaviors are reliably and consistently triggered by different emotions. Because of this reliability and consistency, these physiological changes and motor behaviors became strongly associated with experiences and awareness of emotions in observers. Thus, these physiological changes and motor behaviors not only lead to visually recognizable emotion cues but also auditorily recognizable emotion cues. Just like visual emotion cues, acoustic changes facilitate emotion communication because they reliably indicate the internal state of the communicator. A meta-analysis by Juslin and Laukka (2003) showed that acoustic signals are highly reliable for communicating emotions even across different channels for speech and music.

The current chapter supports that phonemes appear to effectively serve as general acoustic emotion-detection features, with the articulation of different phonemes tending to communicate different emotional states. This is not to say that there are not many other factors that lead to the final interpretation of phonemic sounds, and

clearly, there is a large amount of leeway that has allowed phonetic patterns in words to be defined almost arbitrarily. We are simply establishing that there appears to remain a residual emotional meaning association that prevents phonemes from being entirely neutral, as implied by the traditional atomistic scientific approach. The argument for a universal auditory phonetic-emotion relationship is supported by our experiments showing that the effects occur both across widely different languages and manipulations of facial musculature in multiple languages. Thus, vowel phonemes are not merely neutral abstract building blocks, but rather are salient acoustic markers that likely initially captured important embodied communicative information like the facial musculature associated with emotional state.

Barlow and Gierut (2002) note some features of specific oral configurations that play an important role in the distinction between phonemes such as articulation, voice, place, and manner. The way a speaker pronounces and articulates words is heavily entwined with the overall meaning of what the speaker intends to express, and as such, it is possible that there are similar underlying mechanisms affecting phoneme production. As the production of phonemes is affected, the production of words constructed from these phonemes would then be affected. Our findings that map emotional dimensions onto vowel phoneme space favor the embodied cognition language framework that a strong association between emotional facial musculature and phonetic production likely feeds into language evolution—leading to sound symbolic findings that encompass the entire English lexicon and apply across distinctly different languages.

This change in a fundamental understanding of basic building blocks of language shows promise not only in advancements of research such as linguistics, but also in technological advancements related to speech recognition. Speech recognition technology that works to identify words via acoustic properties generally faces the challenge that as the internal state of speakers changes, so does the set of acoustic properties used to articulate even the same word. Speech recognition technology may be able to perform better by relying on the consistency between musculature activity and resulting acoustic properties for each speaker. Discerning the muscles consistently

involved in a speaker's articulation of the same words may be the next step for speech recognition technology, as researchers look for ways to expand the types of information that is processed (Afouras et al., 2018). Finally, the emotion-phonemic relationship is likely to have an important influence on language development in children. Infant-directed speech, formerly referred to as "Motherese," appears to emphasize emotions in ways that exaggerate the emotional dimensions of valence and arousal (Fadiga et al., 2002; Fernald, 1985***)***. While this may appear to simply be a useful technique to guide the child's attention, our emotion-phonemic model suggests that this might actually be a deeper reflection of basic principles of speech. A better understanding of the emotion-phonemic relationship may therefore be useful in developing general language learning training in both children and adults learning a new language.

In summary, this chapter reviewed the traditional view of vowel phonemes as neutral, abstract building blocks and contrasted that with a new understanding in which they are associated with embodied emotions. We clarify that while many other aspects of speech have powerful effects on the meaning of sounds and that sounds can largely be defined arbitrarily, the body of research suggests that phonemes tend to retain some residual emotional association. We proposed that the same facial musculature that is associated with visually recognizable emotional expressions also favors the production of auditorily recognizable sounds. This led to a common general geometric model that relates phonemes across a variety of metrics including perceptual, acoustic, and biomechanical and emotional. We described the ***Gleam-Glum*** and ***Wham-Womb effects***, respectively, that /i:/-sounds (like "Gleam") are associated with more positive emotional valence than /ʌ/-sounds (like "Glum") and that /æ/-sounds like "Wham" are associated with more arousing emotions than /u/-sounds (like "Womb). We describe supportive research confirming that these emotion-association trends generalize across languages, other species, and manipulations of the facial musculature. This promotes an appreciation of how the emotion-phoneme relationship complements and integrates with other forms of embodied sound symbolism, but provides a stronger functional basis for a broader understanding of language development and evolution. We suggest it may provide a

potential explanation for why humans originally evolved the ability to so finely discriminate the acoustic phonemic characteristics upon which language is scaffolded. In short, phonemes may have initially and still effectively serve as general acoustic emotion-detection features.

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© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_11

11. Location, Timing, and Magnitude of Embodied Language Processing: Methods and Results

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Abstract
In the last 20 years, embodied language has received increasing attention. The role of sensorimotor processes in linguistic comprehension has been investigated extensively with a wealth of neuroscientific methods producing behavioral, neurophysiological, and neuroimaging results. Due to the large variability of stimuli and methods, these studies did not infrequently deliver contradictory or inconsistent results. While this has not undermined the general interest in embodied language processing, it has nevertheless posed serious concerns regarding the reliability of its effects. In this chapter, we take a methodological perspective as a lens to review the existing evidence. We first present behavioral, electrophysiological, and neuroimaging results outlining how these methods have so far answered the question: what are the ***location***, ***timing***, and ***magnitude*** of embodied language processing? Secondly, we will discuss an emerging topic—the one of embodiment in a native and non-native language—

as a case scenario that poses several challenges to the current approach. Finally, we will outline possible avenues for future research.

Keywords Embodiment – Embodied language processing – Linguistic processing – Motor cortex – Sensorimotor cortex – Brain oscillations – Brain stimulation – Motor-evoked potentials – Somatotopy

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Introduction

Embodied language processing has received increasing attention in the last 20 years when arguments have been made that besides the "core" language areas in the left hemisphere, language processing engages neural sensorimotor processes and, therefore, is ***embodied***, involving perception and action circuits (Barsalou et al., 2008; Gallese & Lakoff, 2005; Sakreida et al., 2013; Zwaan & Taylor, 2006). This issue has been investigated with a wealth of methods producing behavioral, neurophysiological, and neuroimaging results (Aziz-Zadeh et al., 2006; Boulenger et al., 2006; Buccino et al., 2005, 2017; Hauk et al., 2004; Gianelli & Dalla Volta, 2015; Kemmerer et al., 2008; Marino et al., 2014; Meteyard et al., 2012; Pulvermüller et al., 2005; for review, see Fischer & Zwaan, 2008, Pulvermüller & Fadiga, 2010). Due to the large variability of stimuli and methods, not infrequently did the studies deliver contradictory or inconsistent results. While this has not undermined the general interest in embodied language processing, it has nevertheless posed serious concerns regarding the reliability of its effects.

In this chapter, we take a methodological viewpoint as a lens to review the existing evidence. We first present behavioral, electrophysiological, and neuroimaging results outlining how these methods have so far answered three key questions:

(1) ***Location***. If we argue that sensorimotor areas are at play during linguistic processing, we have to localize these regions and demonstrate that they are specifically recruited.
(2) ***Timing***. If sensorimotor areas are indeed engaged by linguistic processing, when does this happen? Does this correspond to early or late processing stages?

(3)

> ***Magnitude.*** Even if we can successfully demonstrate that sensorimotor areas are consistently recruited at the early stages of language processing, what's the size of this effect? Does it have any impact on our behavior?

Second, we will discuss an emerging topic—the one of embodiment in a native and non-native language—as a case scenario that poses several challenges to the current approach. Finally, we will outline possible avenues for future research.

Behavioral Measures

Although not directly tapping into brain processes, behavioral measures (e.g., reaction or reading times, and accuracy scores) have been a staple in the research on embodied language processing.

Remarkably, researchers took great advantage of the possibility of directly manipulating the match between action-related stimuli and the motor responses used in the experimental task. In this sense, one of the most widely reported effect was the so-called action-sentence compatibility effect (ACE), where the direction implied by the linguistic stimuli facilitates responses given in the same direction. Glenberg and Kaschak (2002) first reported evidence of the ACE by asking participants to judge whether a sentence was sensible or not by making a response that required a forward or backward hand movement. The authors reported a significant interaction between the direction of the response movement and the movement implied by the respective sentence (e.g., "Close the drawer"). Notably, in this study, the effect was present in a wide range of sentence types such as imperative sentences, sentences describing the transfer of concrete objects, and sentences describing the transfer of abstract entities ("Liz told you the story"). Following this line of research, a large number of additional studies (e.g., Borreggine & Kaschak, 2006; Glenberg et al., 2008; Gianelli et al., 2011; but see Morey et al. in press for a failure to replicate) reported evidence for the ACE in both healthy participants and patients (see García & Ibáñez, 2016, for a review). Importantly, ACE paradigms

typically employ acoustic or visual stimuli presentation where the motor response is not cued and always given once the sentence is fully processed. For this reason, the outcome measure is a reading time that produces evidence in favor of the presence (or the absence) of the ACE but not detailing its ***timing.***

Zwaan and Taylor (2006) cleverly adapted the ACE paradigm to overcome this issue by presenting sentences in segments. Participants had to turn a knob either clockwise or counterclockwise to unfold stimuli presentation. Interestingly, the experiment revealed that participants were faster in reading the sentences if the rotation they implied (e.g., turning the volume on or off) matched the direction of knob rotation.

More recently, de Vega and colleagues (2013) used a visual motion cue to prompt the required hand movement direction to pinpoint the time course of motor system involvement in language comprehension. As in the classic ACE paradigm, participants read sentences describing a transfer either away from or toward their body, but in this case the transfer verb first appeared at the center of the screen and then moved either toward or away as a cue to move their finger in the respective direction. In addition, the onset of the visual motion cue varied (stimulus onset asynchrony (SOA)). The experiment showed that responses were interfered at short SOAs and facilitated at long SOAs implying early motor-language interference but later facilitation compatible with the typical ACE.

It is, however, worth mentioning that while the accumulating results on the ACE are indeed intriguing, their reliability has been recently questioned by a multi-lab replication across several laboratories (Morey et al., in press), including the authors of the original paper and members of our group. Surprisingly, meta-analytic evidence across all laboratories did not show any consistent ACE. It is essential, however, to acknowledge that these results were reported with a procedure that largely deviates from the design used in the original study by Glenberg and Kaschak (2002). Specifically, the replication employed auditory stimuli and the match between sentence direction and movement response (i.e., away or toward the body) was made on a trial-by-trial, not by-block, basis. While the latter was initially intended to maximize the ACE, this has likely undermined

the compatibility effect's motor side by delaying or possibly overriding it. Future research will need to clarify the impact of different procedures on the presence/absence and ***magnitude*** of the ACE, possibly in combination with other methods (e.g., electroencephalography (EEG)), allowing a comprehensive overview of its ***timing***.

While the ACE and similar effects typically require an overt request to plan and execute motor responses, other behavioral techniques allow measuring spontaneous fluctuations in motor behavior reflecting the type and stage of ongoing linguistic processing.

A promising line of research in this sense is the use of grip force sensors to measure the grip force's modulation evoked by processing action words (Aravena et al., 2012, 2014; Frak et al., 2010; Nazir et al., 2017). These sensors are designed to continuously monitor grip force variations as a way of indirectly measuring the motor cortex modulation induced by language processing. In two seminal studies by Aravena et al., (2012, 2014) and Frak et al. (2010), participants were acoustically presented with words or sentences while holding a grip force sensor showing that processing action words significantly increased the grip force level 300 ms after stimulus onset. While promising, this method is still in its early development: future research is needed to clarify whether these results overlap with behavioral measures (RTs and accuracy), although possibly with smaller effect sizes, and how the integration of force sensors with other techniques with high temporal resolution (e.g., EEG, see the exploratory study by Pérez-Gay Juárez et al., 2019) might produce additional evidence as to the ***timing*** of embodied linguistic processing.

Electroencephalography and Magnetoencephalography

As discussed in the previous section, behavioral experiments provided increasing evidence of the interplay between the motor system and language, offering the advantage of measuring motor response while linguistic processing is ongoing. However, they cannot provide any direct insight into ***how*** and ***when*** sensorimotor areas are recruited (Mollo et al., 2016). Using M/EEG can shed some light on this matter by

allowing the measurement of cortical activity even in the absence of any overt movement. This is particularly relevant since this procedure eliminates the possible confound given by requiring readers or listeners to plan and execute movements while also processing linguistic stimuli actively. In EEG, on the contrary, a motor task is typically avoided: this allows targeting any sensorimotor involvement independently from the experimental task. Also, EEG has the advantage of a high temporal resolution (Melnik et al., 2017), allowing the measurement of ongoing processes with millisecond precision (see Fig. 11.1 depicting the spatial and temporal resolution of several methods we review in this chapter).

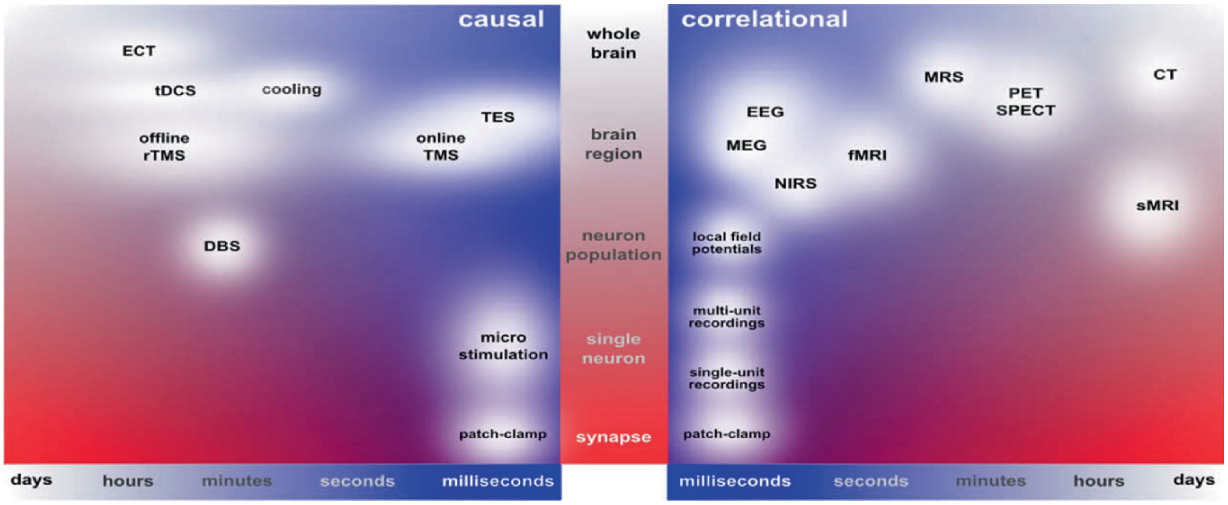


Fig. 11.1 Neurostimulation and neuroimaging techniques arranged according to their spatial and temporal resolution
(Reprinted from Siebner et al., 2009)

In a groundbreaking study, Pulvermüller and colleagues (2001) used current source densities calculated from high-resolution EEG recordings to show somatotopic activation in the motor cortex when processing visually presented effector-specific verbs, such as "to walk." The author showed that processing effector-specific words was mapped onto the same areas usually activated to control the respective effectors. This somatotopic activation started very early, around 250 ms after stimulus onset (see also Kiefer & Pulvermüller, 2012), and, interestingly, showed a peculiar time course of the recruitment of the different sectors of the primary motor cortex. Interestingly, early and effector-specific motor activations were also found when the

auditory stimuli were presented only during a distraction task (watching a silent movie) in an oddball paradigm using MEG (Pulvermüller et al., 2005). More recently, one high-density EEG study employing a semantic decision task found involvement of parietal-frontal networks for action approximately 200–250 ms after concrete action word onset, confirming early and automatic recruitment of the motor system (Dalla Volta et al., 2014).

Interestingly, by combining EEG and kinematics, Boulenger et al. (2008) found that even subliminally presented action verbs during movement preparation modulated the so-called readiness potential—a signature of motor preparation—and affected the subsequent reaching movement. Specifically, subliminal perception of action verbs—compared to concrete nouns—significantly reduced the readiness potential in the movement preparation phase and subsequently wrist acceleration (peak) during the execution one. Overall, this study showed that action verbs interfere with ongoing motor processes even when presented subliminally. Furthermore, the combination of EEG and kinematics revealed the precise time course of such interference.

While the modulation on event-related potentials (ERPs) typically occurs in the early stages of linguistic processing, later effects were also reported when using different measures, e.g., cortical oscillations. Event-related desynchronization (ERD) of alpha (mu rhythm, 8–13 Hz) and beta (15–30 Hz) cortical oscillations as recorded by clusters of central electrodes (e.g., over sensorimotor areas) is a standard measure of motor planning and execution when a voluntary movement is required. Crucially, it is also regarded as a signature of motor processes even in the absence of overt action, e.g., during motor imagery or linguistic processing (Alemanno et al., 2012; Avanzini et al., 2012; Fox et al., 2016). Multiple studies have demonstrated a desynchronization—also referred to as suppression—of these rhythms while processing action verbs (Moreno et al., 2013; Niccolai et al., 2014; Schaller et al., 2017; van Elk et al., 2010). Interestingly, this type of measure allows not only to directly address ***location*** and ***timing*** but also the ***magnitude*** of the reported effects. For instance, Schaller et al. (2017) found effects around 1200 ms after stimulus onset when measuring event-related desynchronization of sensorimotor cortical oscillations. Participants had to process action-related sentences

containing arm-related action verbs in either a concrete or an abstract context. Differences in linguistic processing were predicted by the context in which it took place: while action verbs in a concrete setting elicited desynchronization in the beta range (16–25 Hz) between 1200 and 1400 ms on stimulus onset, action verbs in an abstract setting produced this effect for a more extended period, between 1200 and 1600 ms. In the last section of this chapter, we will show how a similar paradigm has been used to investigate bilinguals' embodied language processing.

Overall, EEG is a robust methodology to pinpoint embodiment effects in language. On the one hand, due to its superior temporal resolution and relative ease of application, EEG/EMG is a method of choice to investigate early, supposedly automatic, motor activations. Moreover, novel source estimation techniques allow localizing the spatial distribution of the EEG signal enabling a more direct comparison with brain imaging data and ruling out possible contaminations by identical frequency ranges associated with other brain activities, such as the occipital alpha typically elicited by visual processing. On the other hand, there is a plethora of various recording and analyzing techniques of M/EEG data, which can make a direct comparison between studies of a complex issue. Another pitfall of EEG studies might be that, in many cases, there is no active motor condition that might help to localize the spatial sources and event-related amplitude changes elicited by actual movement to compare it to the linguistically processed one (Arsenault & Buchsbaum, 2016).

A useful tool to further characterize EEG data is the application of linear discriminant analysis (LDA) classifiers with spatial-spectra decomposition (SSD; Nikulin et al., 2011) and common spatial patterns analysis (CSP; Blankertz et al., 2008). Such classifiers are already used where more accurate signal detection is necessary, such as in studies employing brain computer interfaces (Hommelsen et al., 2017; Tan et al., 2017), allowing the decomposition and analysis of data with the application of machine-learning techniques, which are known for optimizing signal-to-noise ratio, as well as for their simplicity and replicability. For example, a machine-learning algorithm was recently applied to MEG data by García et al. (2019), allowing to disentangle between an early (130–190 ms on stimulus onset) increased motor

activity in response to action verbs and a later (250–410 ms) activation in the anterior temporal lobe (a putative multimodal semantic hub).

The combination of various measurements is also a potentially very promising tool. For instance, Pérez-Gay Juárez et al., 2019 were the first to combine grip force and EEG measurements using the P200 component to pinpoint the cross-talk of action and language. According to Pulvermuller et al. (1999), differences in P200 amplitudes reflect motor associations elicited by action words in motor and premotor cortices as compared to the processing of non-action words. Indeed, the authors found a correlation between grip force modulation and the P200 elicited by listening to action and non-action words while maintaining an active grasping task.

Accessing neural activity in more realistic settings might also help to detect effects that are neglected by single-participant paradigms. With this aim in mind, interactive dyadic settings might deliver interesting insights into language processing's motor effects. Since this remains a challenging issue to solve, attempts have been made to achieve more naturalistic interactions using virtual reality as a controlled setting. In an innovative paradigm, Zappa et al. (2019) measured the participants' EEG activity engaged in a Go/No-Go Task in a naturalistic VR environment. On Go trials, participants had to act on the target object represented by a geometric shape (sphere, cube, cone, cylinder, rectangular prism, triangular prism, hexagonal prism, triangular pyramid), while on No-Go trials, they just listened to a hand or arm verb (e.g., to catch, to push). Significant ERD in both the mu (8–13 Hz) and beta band (20–30 Hz) was found for both Go and No-Go trials in the time window between 400 and 500 ms after verb onset, the former effect being the largest.

Brain Stimulation

At this point, in our chapter, we must acknowledge that while proving the ***location***, ***timing***, and ***magnitude*** of embodied language processing, researchers are constantly faced with an impeding overarching issue: causality. Is the activation of sensorimotor areas necessary and sufficient for language understanding? Does this activation have a

causal role, or is it just a by-product of language comprehension? While other chapters have addressed this topic in more detail, it is worth noting that this issue has been the target of a lively debate (e.g., Mahon & Caramazza, 2008). Indeed, arguments have been made that motor activation is neither necessary nor sufficient for action understanding (Jacob & Jeannerod, 2005).

This issue can be addressed by employing techniques allowing direct and focal stimulation of the target areas, such as transcranial magnetic stimulation (TMS). TMS is a useful tool for proving causal hypotheses and evaluating the direction of the interaction between action and language by being a non-invasive stimulation technique that allows focal stimulation of target cortical areas using strong magnetic fields. Single-pulse TMS (spTMS) protocols deliver a single magnetic pulse at a given time (e.g., at a selected time point for each trial) with no cumulative effects. In contrast, repetitive TMS (rTMS) delivers repeated magnetic pulses at the same intensity producing cumulative effects spanning several minutes after stimulation has been applied.

spTMS is a powerful tool allowing the focal stimulation of the primary motor cortex with millisecond precision coupled with the concomitant recording of motor-evoked potentials (MEPs, measured through surface electromyography) as a measure of cortical excitability. For this reason, spTMS has been widely used for investigating embodied linguistic processing, and particularly the ***timing*** and ***magnitude*** of these effects. Also, it allowed for adding another piece to the puzzle, namely, the ***direction*** of these effects, by providing evidence of MEPs inhibition or facilitation at the neurophysiological level.

Buccino and colleagues (2005) originally found that MEPs recorded from leg and hand muscles produced an effector-related interference induced by the same perception and action systems' simultaneous activation. Participants listened to action sentences referring to a hand movement, foot movement, or abstract content while spTMS was delivered at the end of the second syllable of the verb for each sentence (at 500–700 ms after onset). MEPs' amplitude decreased in hand muscles while listening to hand-related sentences and foot muscles when listening to foot-related sentences. A second study by the same

group showed a similar interference effect only during deep semantic processing of the same sentences (Sato et al., 2008).

Contrary to these results, a replication effort by Gianelli and Dalla Volta (2015) demonstrated an opposite facilitation effect with MEPs recorded from hand muscles increasing when hand sentences were processed. Indeed, multiple other experiments have reported a facilitation effect (Oliveri et al., 2004; Pulvermüller et al., 2005; Scorolli et al., 2012). For instance, Pulvermüller et al. (2005) employed a lexical decision task in which participants were instructed to respond with a lip movement to arm- and leg-related words (e.g., "to pick" versus "to kick") and refrain from responding to pseudowords, with spTMS delivered 150 ms after stimulus presentation. When the pulses were applied on the arm and leg areas, the participants reacted faster to arm and leg words, respectively. Similarly, Innocenti and colleagues (2014) reported increased MEPs at 300 ms after-action word presentation, but this effect disappeared with stimulus repetition. Scorolli and colleagues (2012), instead, reported no difference between abstract and hand-related verbs when TMS was delivered at 250 ms from verb onset in a sentence sensibility task. On the other hand, Papeo and colleagues (2009) showed later effects: MEPs increased at 500 ms for hand-related action verbs during a semantic task compared to non-action verbs, while they decreased at 500 ms during a syllabic task. Recent models suggest that linguistic motor resonance might entail both directions, with the modulation moving from an early interference (within 200 ms) to later facilitation (Chersi et al., 2010; García & Ibáñez, 2016; Marino et al., 2014).

Besides the effect's direction, its specificity appeared to be modulated in a task-related fashion (Papeo et al., 2009). In three different experiments, a TMS pulse was applied at 170, 350, and 500 ms after stimulus onset while the participants decided whether a verb was action related (semantic task) or how many syllables a verb had (syllabic task). At the early lexical-semantic stage (170–350 ms), there was no MEP modulation. At a later, post-conceptual stage (500 ms), hand-related verbs were found to increase motor cortex excitability in the semantic task and decrease in the syllabic one. Motor cortex involvement was thus detected only at late stages of post-conceptual processing, and the type of task modulated the direction of this effect.

Using motor-evoked potentials, we recently (Gianelli et al., 2020) showed the same motor inhibition pattern (i.e., a decrease of MEPs compared to baseline) in response to visual and linguistic stimuli. Stimuli were pairs of sequentially presented pictures (tool + tool-oriented hand action) and words (tool noun + tool-action verb), and spTMS was applied to the left motor cortex at five different ***timing***s: baseline; 200 ms after tool/noun onset; 150, 350, and 500 ms after hand/verb onset with MEPs recorded from two target hand muscles (FDI and ADM). Interestingly, the MEP suppression pattern lasted for the whole duration of stimulus presentation with an initial onset as early as 150 ms after stimulus presentation (tool-oriented hand action or tool-action verb).

While this might seem at odds with previous evidence from our group (Gianelli & Dalla Volta, 2015), the two results are complementary rather than contradictory. While in Gianelli and Dalla Volta (2015), MEPs facilitation for hand-related sentences resulted from the comparison with the abstract and foot-related ones, Gianelli et al. (2020) included a proper baseline condition. Also, while the former presented full sentences with the noun at the end of the sentence ("He wrote the letter"), the latter used a paradigm in which the noun preceded the verb. As the noun was always referred to hand-related tools, this produced—numerically, although not statistically—a motor activation that preceded spTMS during verb processing. This likely induced complex corticospinal dynamics where near-threshold motor activations resulted from the additive effects of noun and verb processing produced a strong inhibitory drive to prevent actual movement execution. Supporting this view, we reported the same results for both the linguistic and visual modalities, pointing to a core system of action semantics.

While spTMS allows direct detectable motor output measures, this can be done only on a trial-by-trial basis. rTMS, on the other hand, allows for affecting the target areas for more extended time windows in which possible impairments of linguistic or motor processing—which would strongly imply a causal involvement of sensorimotor and other areas—can be tested.

In this vein, Willems and colleagues asked participants to perform a lexical decision task on verbs describing either actions typically

performed with the dominant hand (e.g., “to write”) or non-manual actions (e.g., “to wander”) (Willems et al., 2011). When the hand area in the left premotor cortex was stimulated with continuous theta-burst stimulation (cTMS), the responses were faster in the former condition, providing concrete evidence of the causal involvement of motor areas in language processing and further studies corroborated this idea (Gijssels et al., 2018; Vukovic & Shtyrov, 2019). In a recent study, Vukovic, and Shtyrov (2019) instructed participants to learn novel action verbs and object nouns (pseudowords) in a virtual reality setting within an interactive computer game presupposing the use of 3D objects. In the experimental condition, cTMS was applied to the subjects’ motor cortex 5 min before the learning phase. In two other conditions, either TMS on the right superior parietal lobule or sham stimulation was applied. Indeed, cTMS disrupted learning, as measured by learning accuracy and movement kinematics (i.e., path complexity).

Overall, TMS offers the great advantage of allowing the focal stimulation of selected brain areas with millisecond precision. When targeting the primary motor cortex, TMS enables the quantification of motor effects and investigation of their timing concerning sentence or word processing. When used repetitively, TMS also allows targeting other brain areas and testing their causal involvement in linguistic processing. It has to be noted, however, that TMS requires precise localization of target areas as well as taking into account the impact of this stimulation on the functional network recruited by the specific stimuli or tasks. Studies employing combined neuro-navigated TMS and EEG show promising results and will undoubtedly constitute one of the future avenues of embodied linguistic processing. Furthermore, when intended to investigate the ***direction*** of motor effects, experiments should include appropriate baseline conditions (see Gianelli et al., 2020).

Functional Brain Imaging

Because of its superior spatial resolution, functional magnetic resonance imaging (fMRI) allows precise localization of the effects of embodied language processing in specific regions of interest. fMRI was indeed among the first techniques used to study embodied effects in

language processing, as it allowed proving not only the involvement of sensorimotor areas but also their ***location*** in terms of somatotopic motor activations. Somatotopy was, in fact, considered a requirement to support an embodied view: if the same sensorimotor systems serving action execution are involved in linguistic processing, then this should happen in a somatotopic fashion. Hauk et al. (2004) first demonstrated that passive reading of face-, arm- and leg-related words induced a somatotopic activation in the motor cortex similar to that elicited by performing actions using the respective effectors (see Fig. 11.2).

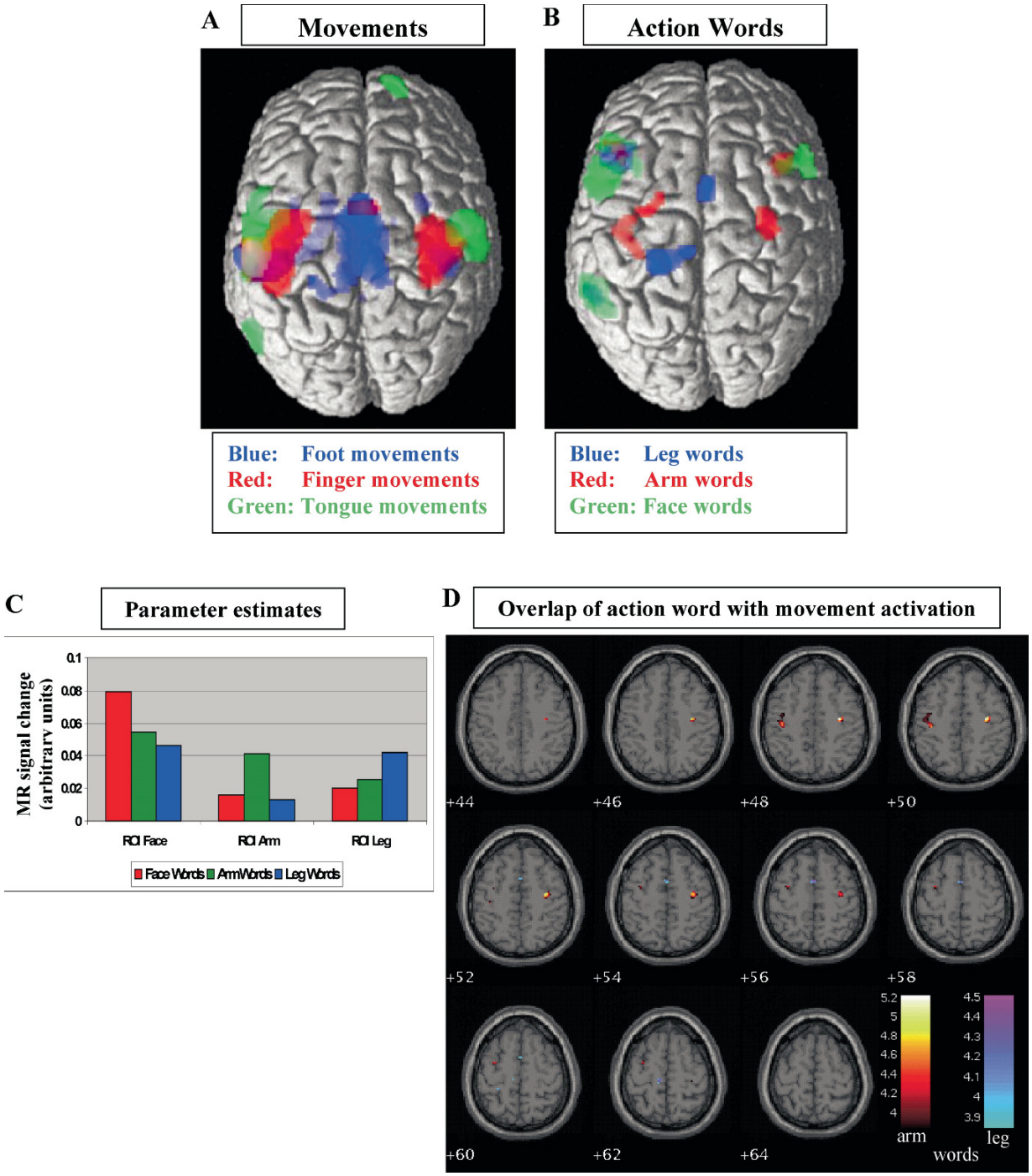


Fig. 11.2 Brain areas activated by subcategories of action words and movement execution (Reprinted from Hauk et al., 2004)

Along the same line, Tettamanti et al. (2005) presented sentences referring to actions performed with the mouth, the hand, or the foot and clearly showed the involvement of a frontoparietal circuit. Interestingly, stimuli evoking hand actions activated the left precentral

gyrus, the posterior intraparietal sulcus, and the left posterior inferior temporal area. Differently, leg-related stimuli activated the left dorsal premotor and left intraparietal sulcus, but located more dorsally and rostrally compared to hand actions. Several other studies later supported these findings (Aziz-Zadeh et al., 2006; Boulenger et al., 2008; Kemmerer et al., 2008; Tettamanti et al., 2005).

Interestingly, these effector-related activations proved to be quite specific, as they also likely reflect individual characteristics, such as handedness. Willems et al. (2010) used a lexical decision task to investigate whether activation in the motor and premotor cortices while processing manual action verbs was different in left- and right-handers. The authors indeed found a preferential activation of the left premotor cortex for right-handers and, vice versa, of the right premotor cortex for left-handers.

Remarkably, somatotopic motor activations do not seem limited to action-related stimuli, but could also be originated when fictive motion is implied (e.g., the blood runs), according to the linguistic context in which it is embedded, as shown by Romero Lauro and colleagues (2013). However, in another study by Raposo and colleagues (2009), participants listened to arm- and leg-related verbs presented in isolation (e.g., ***kick***), in literal sentences (as in ***kick the ball***), and idiomatic sentences (as in ***kick the bucket***) and the authors showed consistent activations in motor areas for both verbs in isolation and verbs in literal contexts, although with differences in ***magnitude*** in favor of the former. No involvement of the motor system was found when processing verbs in the idiomatic contexts. Crucially, a recent meta-analysis by Yang and Shu (2016) supports the activation of premotor and motor regions in processing idioms, with differences in the experimental manipulations as a possible explanation of diverging results.

Although fMRI has been successfully used to study motor effects in language comprehension, possible limitations should be considered when taking ***localizing*** as the primary target. As Haynes (2015) points out, the information contained in voxel analysis can be either under- or overestimated since the sampling of neural activity made by fMRI voxels is highly indirect. Direct comparison of different brain regions is also limited due to the various sizes, the number of voxels, and signal-

to-noise ratio in each area. A multivariate pattern approach to non-smoothed data can help overcome these limitations (Horoufchin et al., 2018).

An Example: Is Embodied Cognition Bilingual?

After reviewing evidence on embodied language processing gathered with different behavioral and neuroscientific measures, we aim to close our chapter by briefly presenting an emerging topic in the field as a proof of concept.

The evidence discussed so far—and by extension, a large part of the data currently available—tested embodied linguistic processing in native speakers (L1). Evidence on embodiment in the second language in sequential bilinguals (L2, see, Kühne & Gianelli, 2019 for a review) is still quite limited. In sequential bilinguals, learning of L2 follows L1 with a time course that is shifted with respect to the acquisition of sensory and motor control. Even when high proficiency is reached in L2, does this lag between linguistic and sensorimotor processes hinder embodiment at some level? Do we rely on embodied processes at all when L2 is involved? Undoubtedly, this topic constitutes a theoretical and experimental challenge. At the theoretical level, approaching L2 allows to directly test different models, particularly those pertaining to a strong or a more flexible view of embodied language processing. On the one hand, according to strong views of embodied cognition L1 and L2 processing should rely on similar—possibly fully overlapping—mechanisms. This would posit that L1 and L2 are equally grounded in sensorimotor processes, in such a way that the same behavioral, motor, and neural effects would become evident regardless of the language in use. On the other hand, a more flexible view would predict that differences in these effects' timing, location, or magnitude would emerge in L2 compared to L1, as a result of different times of acquisition producing the aforementioned temporal shift between sensorimotor and linguistic development. As a direct consequence, the challenge at the experimental level should become evident: how can we test these hypotheses and provide data capable of providing a full account of L2 embodied linguistic processing?

The first necessary step would be to show that processing the same stimuli in L1 and L2 produces comparable activations, primarily in motor regions, thus accounting for their ***location***. Rüschemeyer and colleagues (2006) showed with fMRI that a semantic violation produces comparable activations in the left inferior frontal gyrus (***location***) in both L1 and L2 speakers, but interestingly with larger effects for L2 speakers (***magnitude***). Similarly, De Grauwe and colleagues (2014) proved that processing simple action verbs engages motor and somatosensory regions in both L1 and L2 in a lexical decision task.

While intriguing, these results do not, however, produce any evidence regarding the ***timing*** of L1 and L2 processing of action-related stimuli. A difference in ***timing*** and/or ***magnitude*** between the two might offer interesting theoretical insights. Data from M/EEG or TMS would be highly relevant to this aim, but current results are limited and somewhat divergent.

Vukovic and Shtyrov (2014) produced EEG evidence of a crucial quantitative difference between L1 and L2 on top of substantially qualitative similarity. In this study, the authors measured event-related desynchronization of the mu rhythm as an index of changes in the cortical motor system's activity induced by processing action-related stimuli in German (L1) and English (L2). Indeed, the study showed that, while ERD's onset was quite early (150 ms after stimulus onset) in both languages, the ***magnitude*** of this effect was larger for L1 than L2. Interestingly, source estimation suggests that the neural generators of ERD were the same in L1 and L2 (see Fig. 11.3).

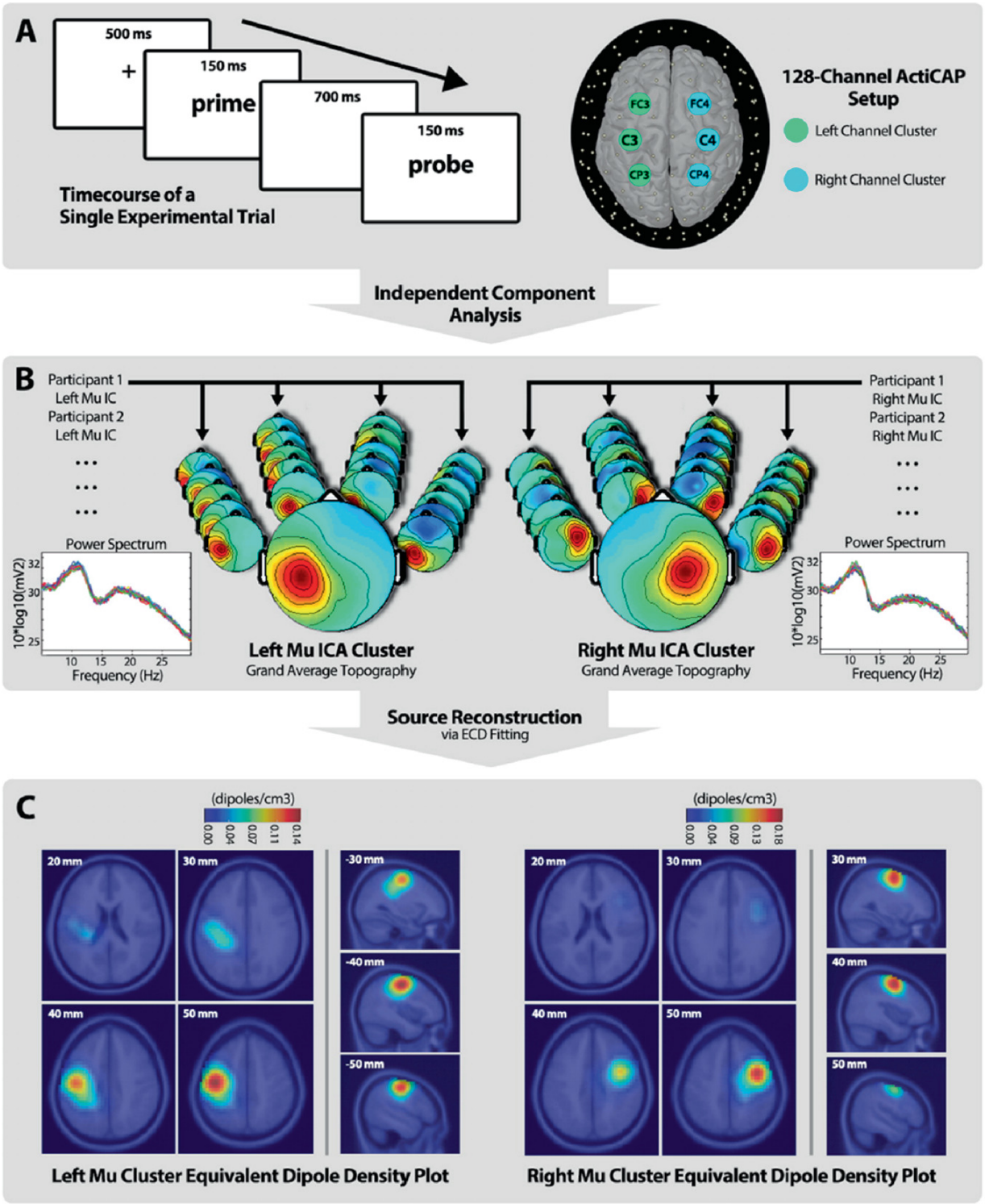


Fig. 11.3 Experimental setup and results of independent component analyses in the study by Vukovic and Shtyrov (2014)

Our group has recently tackled this issue employing brain stimulation (Gianelli et al., 2020). In two experiments, we applied

spTMS over the primary motor cortex at different ***timing***s before and during the processing of action-related stimuli presented visually and linguistically to sequential bilinguals (in German as L1 for Experiment 1 and English as L2 for Experiment 2). Crucially, we showed the same modulation of cortical excitability—as indexed by MEPs—in both L1 and L2 with the same time course. Notably, the pattern of cortical motor dynamics in the linguistic modality was comparable to the visual one: this argues favoring a shared system of action semantics across modalities and languages. It is worth noting, however, that both studies involved participants with good and very good L2 proficiency—as well as the behavioral study by Buccino et al. (2017). It is indeed possible that different degrees of proficiency might drive or modulate the reported effects when adequately taken into consideration. While these data are only preliminary, the similarity in motor activations is particularly intriguing as it points to shared processes in L1 and L2, with L2 building on the existing sensorimotor experiences from L1 (e.g., Foroni, 2015).

However, differences in ***magnitude*** or ***timing*** might point to a partially divergent functional role, with embodied linguistic processing coming into play during the learning phase of L2 as a supporting system that is later differentially activated according to the degree of proficiency and (action) fluency. Future research directly comparing different groups of native and non-native speakers and learners at different stages of L2 appraisal will be needed to clarify this issue. A careful experimental design, possibly combining additional measures accounting for ***location***, ***timing***, and ***magnitude*** of these effects, will be crucial to disentangle the role of embodied linguistic processing in L1 and L2.

Conclusions and Outlook

In this chapter, we briefly reviewed the current evidence on embodied language processing gathered by behavioral and neuroscientific methods. Overall, we have clearly shown that research on the ***location*** of sensorimotor activations has so far mostly focused on motor and premotor areas with the aim of showing somatotopic, effector-related activations. More recently, a broader approach has been taken to

disentangle the role of a broader cortical network in driving embodied effects while processing relevant stimuli. As to the ***timing*** of these processes, the debate is still ongoing as diverging results emerged. While there is general agreement that the effects measured by EEG, or by recording motor responses, can occur in the very early stages of linguistic processing, it appears that the exact time course depends not only on stimulus type but also on task demands. Finally, as to the ***magnitude*** of these effects, methods allowing the quantification, besides the qualification, of sensorimotor activations are increasingly being used. We have shown the example of embodied linguistic processing in bilinguals as a case scenario where such an approach might be beneficial and possibly solve some longstanding debates. Finally, we remark that the ***context*** is emerging as the hidden factor that current and future research should take into consideration. Contextual information, including task demands, certainly affects ***timing*** (see Beauprez et al., 2018) and ***magnitude*** (Courson et al., 2018), but possibly also ***location.*** The combination of different methods, a promising yet still under-explored avenue in this domain, will undoubtedly be a powerful tool in this sense.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_12

12. Embodied Attention: Integrating the Body and Senses to Act in the World

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Abstract
Research on spatial attention traditionally focuses on how it is influenced by the location of objects within the visual environment and by expectations about those objects. However, a primary function of spatial attention is to plan physical actions. When events occur in the world, visual information needs to be gathered and integrated with current body position to help prepare effective responses to these events. Further, current actions can subsequently influence future deployments of attention. Thus, spatial attention must be considered within the context of bodily actions. Here, we review research demonstrating that one's own body and actions and the actions of others can affect spatial attention mechanisms, influencing the prioritization of functional space near the body and governing the deployment of attention. This work emphasizes a need for an embodied theory of spatial attention and a more dynamic neural model of attention, attention that adjusts to meet the affordances of the body and of the current environment and, at the same time, the perceiver's goals.

Keywords Spatial attention – Embodiment – Covert orienting – Human body – Hand proximity effect – Multisensory integration – Functional action

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Research traditionally focuses on how spatial attention is influenced by the location of objects within the visual environment but neglects to consider that its primary function in the natural ecology is to facilitate functional actions. When events occur in the world, sensory information needs to be integrated with information about current body position to help prepare effective responses to these events and these responses in turn influence the direction of attention. Thus, spatial attention must be considered within the context of the body. Here, we review behavioral and neurological research to emphasize the embodied nature of attention. One's own body and the actions of others can influence spatial attention mechanisms, influencing the prioritization of functional space near the body and the direction of attention. This concept of embodied attention emphasizes the role of attention in integrating the body with sensory processing and explores how changes in bodily function can affect subsequent perceptual and cognitive functioning. Finally, we propose the need for a more dynamic neural model of attention that adjusts to meet the affordances of the body, the demands of the current environment, and the perceiver's goals.

Our views fit naturally into a long historical tradition following from the functionalist philosophy of James (1890/1983) with its origins in Darwin's theory. They follow, too, from the ecological psychology of Gibson (1979), a student of a student (E. B. Holt) of James. Gibson argued that much of human behavior was determined not by higher cognitive functioning but, rather, by the complementary affordances of the physical world and the human body. The physical world permits certain actions and, of those, some are also permitted by the human body. In our view, attention operates under and exploits those constraints. Our views are also very similar to the close integration of vision and goal-directed action elaborated by Hayhoe and colleagues (for a review, see Hayhoe, 2017). Here, we focus not on vision per se, but instead on attention, the preparation for action that

precedes movement of gaze or other movement toward a goal. We generally take a view that attention is embodied. By this we mean that the control of attention "must be understood in the context of its relationship to a physical body that interacts with the world" (Wilson, 2002, p. 625). In this chapter, we take the relatively narrow view of embodiment that cognition is situated or grounded (see Wilson, 2002, Claim 1), but remain agnostic about broader claims that most if not all cognition—including imagery, memory, reasoning, and language—is body based (e.g., Barsalou, 2008; also see Wilson, 2002, Claim 6).

Introduction

The ability to interact effectively with one's environment requires processing sensory information in the service of planning and executing meaningful actions (Previc, 1998; Prinz, 1997). In our everyday world, we need to know how to respond effectively to the task at hand, whether an enemy throws a rock at our head which is to be dodged or a friend tosses us a ball which is to be caught. The current location of our hands in these situations influences the speed and success with which we can either knock the rock away or grab the ball. These common examples emphasize the dynamic nature of the environment and the need for our spatial attention system to effectively integrate visual information with information from our own bodies.

Spatial attention refers to the cognitive process through which certain visual stimuli are selected to the exclusion of other stimuli based on their spatial location (Tipper, 2004; Vecera & Rizzo, 2003). One of the primary functions of spatial attention is to select for processing objects and locations in space that are functionally relevant to what an organism is doing now (Tipper, 2004) or will be doing sometime in the near future. To interact successfully with the environment, one must orient attention to relevant events. Spatial attention helps us select the most relevant task information and aids perceptual and cognitive processing by amplifying signals associated with salient or important regions of space (Braun et al., 2001; Pashler, 1998; Posner & Cohen, 1984). Moreover, given that the current orientation of our bodies and the positions of our appendages provide

an anchor or point of reference for current and upcoming action, the body and its limbs may aid in the selection of relevant perceptual information. Most research has explored how the properties of the objects themselves (such as sudden appearance of an object) or our intentions (such as looking for a 'T' among a field of 'L's) guide attention. Although it makes sense that our bodies and actions should play an important role in the operation of spatial attention processes, less research has investigated how our bodies and actions influence attention.

This functional view of spatial attention has important implications for how sensorimotor experience, the body, and its actions influence our visual perception. Skilled activity requires the integration of past, present, and future events. Performers need to acquire perceptual information to determine the outcomes of past actions, to monitor on-going actions, and to plan how to respond to upcoming events. At the same time, performers are producing their own activity that is based on this information and contributes to the available perceptual information. One way in which spatial attention can influence this dynamic interaction between top-down goals of what one intends to do and bottom-up influences from the environment is by prioritizing processing in certain regions of space near the body where most actions, planned actions, and reactions take place.

This perspective implicates a dynamic, multimodal, whole-brain network in attentional processing. Desimone and Duncan (1995) have proposed a ***biased competition model*** in which selective visual attention is an emergent property of competitive interactions that work in parallel across visual space. Objects compete for limited processing resources and control of behavior. This competition is biased by both bottom-up and top-down inputs. Bottom-up mechanisms help to distinguish objects from their backgrounds. The underlying neural mechanisms associated with more bottom-up biases for resolving competition among multiple ***objects*** involve the visual ventral stream that connects visual cortex with inferior temporal cortex (Ungerleider & Mishkin, 1982). Neural mechanisms involved in resolving competition for several relevant ***locations*** in space involve the dorsal stream connecting visual cortex with parietal regions. Top-down mechanisms help select regions of space and objects that are relevant

for on-going behavior. Top-down selection for both objects and locations is thought to be derived from the prefrontal cortex and from neural circuits mediating working memory. Further, medial temporal and hippocampal regions provide information that permits past experience to inform future actions.

Here, we extend this dynamic model of attention to include influences of the body and its actions. We propose that neural circuits involved in determining the current position of the body prioritize spatial locations for upcoming functional interactions. Thus, current active behavior should be included in the biased competition model of spatial attention. The addition of the neural substrates representing the body and its actions creates a more dynamic model in which attention constantly adjusts to meet the demands of the current environment and the perceiver's goals. Under this view, spatial attention emerges as a distribution or topography of activation across visual space within which the body and its actions serve to increase relative activation near functional effectors, shift the location of relatively high activation regions to those relevant to bodily action, and implement action goals.

In this chapter, we examine research that explores involvement of the body and its actions in spatial attention processes. First, we will examine how the orientation, location, and functional properties of our own body parts can shape the allocation of attention and prioritization of certain regions in space. Next, we will consider how attentional mechanisms change to incorporate the body in action. Finally, we consider how our perception of other people's bodies and their actions or implied actions can influence our future oriented behaviors. Together this research argues for an embodied model of spatial cognition that helps explain how we predict and respond to the dynamic world around us.

How Do Our Own Bodies Influence Attention?

An embodied theory of spatial attention proposes that our bodies influence the distribution of attention in space and the subsequent processing of sensory, especially visual, stimuli. At any moment, the current position of our body and the configuration of our body parts

constrains possible action. This theory would predict that the static body and its positions would influence where spatial attention is allocated across visual space. Moreover, it would predict that the functional actions of the body would affect attentional processing.

Static Effects of Hands and Effectors on Attention

Our effectors influence processing in regions of space in which they can perform functional actions. Integrating information about our current body position from tactile and proprioceptive systems with visual information regarding the world around us is critical for performing functional actions such as picking up a cell phone or catching a ball. Hands have an important influence on attention because they provide our primary means for interacting with the world. Further, because it is the space in which we perform actions, space near the palm may command a disproportionate amount of attentional resources. The current configuration of sensory and effector organs necessarily affects the way that actions are performed to accomplish our goals. For example, to grasp a visually detected object one needs to know not only the object's location relative to the eye but also its position relative to the hand in order to plan an appropriate reach. To perform this functional action, a sensorimotor transformation is required to integrate current information regarding the placement of the hand and arm relative to the orientation of eye and head (Biguer et al., 1985; Karnath, 1997). Thus, the location and functional properties of exploring effectors such as the hands should influence spatial attention mechanisms.

Physiological recordings from non-human primates have identified populations of neurons that respond to both tactile stimuli on the hand as well as to visual stimuli near the hand. In macaques, bimodal visuotactile neurons are distinguished by their characteristic response properties in peripersonal space (i.e., space near the body) (Fogassi et al., 1992, 1996; Gentilucci et al., 1988; Graziano & Gross, 1993, 1994, 1998; Iriki et al., 1996, 2001; Obayashi et al., 2000; Rizzolatti et al., 1981). These neurons not only respond to tactile stimulation on the hand but also to visual stimuli appearing on or near the hand (Graziano & Gross, 1993, 1994). They also have spatially graded responses in that the size of the response decreases as the visual stimulus appears

progressively further from the hand. Further, these responses are specific to the hand and do not occur when the subject's arm is located away from the target, or when an artificial arm is placed near the visual target (Graziano et al., 2000).

Bimodal neurons appear to encode space based on hand-centered coordinate systems. That is, the neuronal response is based on the position of the visual stimulus relative to the hand, not the position of the visual stimulus in space. These visuotactile neurons integrate multimodal sensory information in near visual peripersonal space that surrounds specific body parts such as the hand. Thus, visual stimuli appearing near the hand may elicit activation from bimodal neurons that respond specifically to regions on and near the hand, from visual neurons representing visual inputs, and from proprioceptive neurons representing limb position. As a result, visual stimuli appearing in space near the hand may produce a stronger overall neural response than visual targets appearing far from the hand that do not engage bimodal neurons.

Further, neurophysiologists have argued that visuotactile bimodal neurons are important for action. In non-human primate cortex, bimodal neurons are found in areas associated with action and action planning, such as the ventral premotor cortex, putamen, ventral intraparietal sulcus, and cortical areas 6 and 7b (Graziano, 2001). These cortical and subcortical regions form a multimodal neural network that coordinates visual and tactile–motor systems when interaction with the world is required (Fadiga et al., 2000).

Evidence supporting the existence of bimodal neurons in human brains comes from cross-modal extinction studies of patients with right parietal lobe damage (di Pellegrino et al., 1997; Farne & Ladavas, 2000; Farne et al., 2000; Ladavas, 2002; Ladavas et al., 1998a, b). Tactile extinction refers to an inability to perceive a contralesional tactile stimulus when a competing ipsilesional tactile stimulus is presented simultaneously. Supporting the existence of bimodal representations of peripersonal space, these patients demonstrated cross-modal extinction in which a visual stimulus presented near the unaffected ipsilesional hand induced the extinction of a tactile stimulus presented on the contralesional hand; however, an identical visual stimulus at the

same location in space did not elicit cross-modal tactile extinction when the ipsilesional hand was absent.

Additional evidence supporting the role of bimodal neurons for integrating sensory and body inputs comes from behavioral and neurophysiological data from neurologically intact individuals. A number of behavioral studies have demonstrated that visual processing is influenced by hand location, even when the hand is completely irrelevant to the task (for reviews see Brockmole et al., 2013; Tseng & Bridgeman, 2012; Abrams et al., 2008; Bush & Vecera, 2014; Cosman & Vecera, 2010; Davoli et al., 2012; Gozli et al., 2013; Grubb & Reed, 2002; Reed et al., 2006, 2010; Thomas, 2015). To demonstrate what is now known as the hand proximity effect, Reed et al. (2006) used a modified covert orienting task (Posner & Cohen, 1984) in which participants held one hand next to one of two lateralized target locations and indicated target detection via a button press with the opposite hand (Fig. 12.1). Hand location changed attention to the space near the hand: participants were faster to detect targets appearing next to the hand, regardless of cue validity. This facilitation depended on the hand's physical proximity to the target location, and it did not occur when an arbitrary visual anchor replaced the hand (e.g., a 2″ × 4″ board approximately the same size as the arm and hand). Further, the effect appeared to be multimodal in that it occurred even when direct visual inputs of hand location were blocked (i.e., vision of the hand was occluded) or direct tactile/proprioceptive inputs were removed (i.e., a gloved fake hand was placed next to the screen and the observer wore a glove).

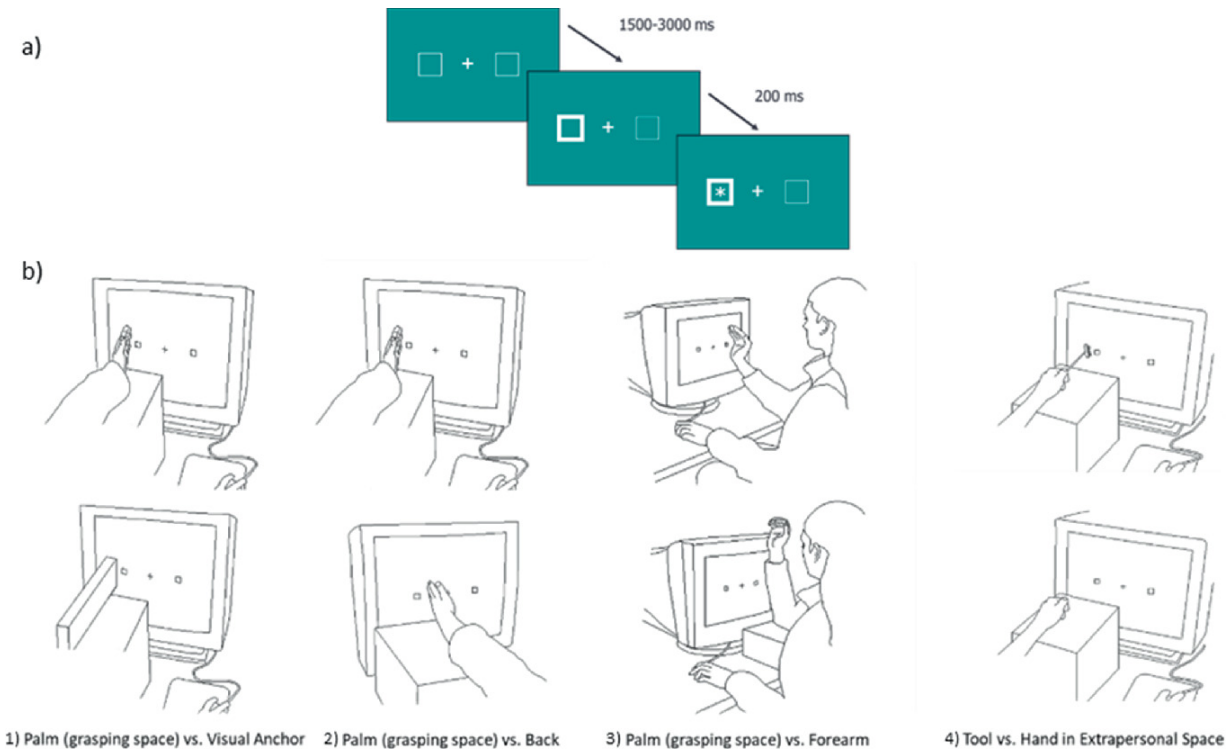


Fig. 12.1 a Example valid trial sequence from the covert orienting paradigm; b illustrations of experimental conditions: (1) Palm versus visual anchor; (2) palm versus back of hand; (3) palm versus forearm; and (4) tool versus far hand (from Reed et al., 2006, 2010)

These findings are consistent with the properties of bimodal neurons and suggest that in addition to the visual neurons typically used to perform the task, bimodal neurons, presumably in frontal and parietal cortices that respond to tactile or visual stimuli presented near various body parts, may be involved in detecting targets appearing near a body part (Graziano & Gross, 1993; Graziano et al., 1994; Rizzolatti et al., 1981). The space near the hand appears to be represented bimodally in terms of both visual and proprioceptive/tactile inputs, which may drive facilitation effects by amplifying signals from that location. Such an amplification would ultimately increase the signal to noise ratio for stimuli near the body, thereby improving response times and target detection to stimuli.

The influence of hand placement on visual processing has also been demonstrated in brain-damaged patients (Buxbaum & Coslett, 1998; Coslett & Lie, 2004; Schendel & Robertson, 2004). Buxbaum and Coslett (1998) report a patient with a distinct form of optic ataxia in which he had difficulty fixating or attending to locations where he was not

reaching. His attention seemed to be captured by his hand position and was directed by his reaching action. Coslett and Lie (2004) found that tactile extinction in two patients with right parietal damage was alleviated in the contralesional hand when the ipsilesional hand was positioned proximal to it. Finally, Schendel and Robertson (2004) reported a patient with a left hemianopsia whose left hemifield vision loss was attenuated when his left hand was held up, proximal to the target locations in the left hemifield. This facilitation was dependent on the proximity of the hand to the target locations, suggesting an enhancement of visual processing for stimuli appearing in the space surrounding the hand.

In addition to simple proximity of objects to the effector, the hand's potential for acting on visual objects appearing near the hand also influences processing. The actions one uses to interact with an object in front of the palm are different from those required for an object behind the back of the hand. For example, an object in front of our palm is easily grasped, unlike an object that is located at the same distance from the back of our hand. Several studies have shown that visual processing is modulated by hand position and functional capabilities (Reed et al., 2010; Thomas, 2015; Vyas et al., 2019). Most research investigating the effects of hand proximity on visual processing and attention, however, has compared conditions in which the hand is placed either near or far from the visual stimulus. Further, in hand-near conditions visual stimuli are located in front of the palm in "grasping space." Only a few studies have investigated how hand-near conditions that vary the ease with which the hand can grasp or potentially act on visual stimuli influence attentional and perceptual processing.

In one such study, Reed et al. (2010) demonstrated that facility of visual processing was related to the functional properties of the hand. Using a covert-orienting paradigm, they compared conditions in which either targets appeared near the palm (i.e., in grasping space) or they appeared the same distance behind the hand. Targets appearing near the palm produced faster responses than targets appearing near the back of the hand. In addition, palm-side facilitation was found regardless of whether orienting cues were predictive or non-predictive of target location (Garza et al., 2013). Thus, the topology of the facilitated space around the hand appears to be defined, in part, by the

hand's potential to grasp visually presented objects. This same study showed that this facilitation could be extended beyond the hand to the end of a rake, but only after participants had used the rake. In addition, an analogous functional topography of the spatial prioritization was also observed for targets appearing near the prong-side of the rake rather than near the back side of the rake. Thus, the spatial prioritization observed in these studies appears to be functionally related to the affordances presented by the presence of the hand or a tool, after functional interaction with it.

More recently, Thomas (2015) demonstrated that hand proximity effects were not only related to the hand's ability to interact with objects but also that specific hand postures and affordances differentially affected global motion and form perception: A power grasp posture (i.e., using all digits) improved relative performance on a visual motion detection task, but a precision grasp posture (i.e., using primarily thumb and index fingers) improved relative performance on a form perception task. It appears that the visual system alters processing based on the hand's potential to perform specific actions: Power grasps that are used for fast and forceful interactions with objects result in improved temporal sensitivity and precision grasps that are used to perform specific movements with parts of objects result in improved spatial sensitivity. Further, Bush and Vecera (2014) demonstrated that the proximity of one versus two hands in power grasp postures can affect the relative benefits of form over temporal processing: It appears that a single hand configured in a power grasp posture is able to narrow the focus of attention for form processing. These studies are consistent with the proposal by Gozli and colleagues (2012) that hand proximity and the ways we use our hands affect visual processing through differential contributions from the magnocellular (object processing) and parvocellular (location and movement processing) pathways, which in turn may lead to the activation of ventral versus dorsal stream processing, respectively (Davoli et al., 2012; Tseng & Bridgeman, 2011).

Of interest, the ability of the hand to perform functional actions extends to other effectors such as the feet. Stettler and Thomas (2017) found similar biases in visual processing for objects near the feet as for those near the hands. Participants performed attentional cueing tasks

in which they detected targets appearing near and far from a foot, a non-foot visual anchor, or an occluded foot, analogous to the hand manipulations in Reed et al. (2006). Faster response times were found for targets appearing near the visible foot but not the occluded foot or for a non-foot anchor. As with the hand, objects appearing in functional stepping or kicking space near the foot appeared to be processed differently from those distant from the foot.

Together, these studies suggest that spatial attention incorporates multimodal inputs and the functional properties of the hands and feet to change the distribution of attention across peripersonal visual space. Further, objects used to manipulate space outside of normal reach are easily and rapidly assimilated into body space. Additional neural systems are very likely recruited to facilitate perceptual processing when the body is relevant to attentional allocation. This work is consistent with the biased competition model (Desimone & Duncan, 1995) and extends that purely visual model to include systems for processing multimodal inputs.

Effects of Effector Action on Spatial Attention

Above, we presented research indicating that static hand position can influence the processing of functional space near the hand. Here, we consider how action changes attentional allocation in functional space. Executing an action is a dynamic process and attention changes dynamically. Several studies have documented that the hand's ability to perform actions affects the visual processing and attention for objects near the hand, suggesting that actions may have specific effects on visual orienting.

Although most research investigating the relation between spatial attention and action focuses on actions as responses to visual attention manipulations, Garza et al. (2018) examined visual attention immediately following an executed or imagined action. Using a modified spatial cuing paradigm, they tested whether a brief, lateralized hand-pinch performed by the individual's non-visible hand near the target location facilitated or inhibited subsequent visual target detection. Conditions in which hand-pinches were actually executed (action) were compared to those with no hand-pinch (inaction) and imagined pinches (imagination). Actual and imagined

hand pinches facilitated rather than inhibited subsequent detection responses to targets appearing near the pinch, but target detection was not affected by inaction. These results highlight the dynamic nature of visual attention and how actions can be cues for additional actions as well as responses.

Neural Correlates of Effector Location and Action Influences on Attention

Behavioral studies suggest that visual attention is biased toward stimuli in the functional region of space near the palm of the hand, which integrates tactile, proprioceptive, and visual inputs. However, behavioral studies cannot distinguish early sensory integration from later, as goal relevant, or task-related, attentional processes. In a series of studies, Reed and colleagues measured event-related-potentials (ERPs) using visual detection tasks that manipulated proximity of the hand to the visual stimulus (Reed et al., 2013), reliance on proprioceptive information for hand location (Reed et al., 2018), and functional hand capabilities (Vyas et al., 2019). Reed et al. (2013) investigated the timing and relative contributions of hand proximity to sensory and cognitive processes using ERPs. Specifically, they used the temporal resolution of EEG to explore whether hand proximity effects were relatively early, reflecting processes that preceded identification of a stimulus as goal-relevant or processes that followed identification or both, using a 50/50 go-nogo target detection task.

The most robust findings of hand proximity effects on target processing were found at N1 (120–190 ms post stimulus) and P3 (350–450 ms). N1 is a negative deflection over posterior sites that is assumed to reflect selective attention to basic stimulus characteristics, initial selection for later pattern recognition, intentional discrimination processing, and multisensory integration (e.g., Kennett et al., 2001; Simon-Dack et al., 2009; Vogel & Luck, 2000). P3 reflects discrimination of stimulus categories at a more abstract, task or motivationally relevant level. It is typically maximal over centroparietal regions and is produced by a number of cognitive factors, including allocation of attentional resources and categorization of events (Kok, 2001). The P3 response to stimuli can vary by category at a very high level, for instance, on the basis of high

vs. low motivational value (e.g., Leland & Pineda, 2006, 2011). Reed et al. (2013) concluded that later in processing, when task-related attention is able to classify the stimuli, hand proximity affects only those stimuli that are relevant for action, namely targets. The presence of two distinct post-categorical effects, one relatively early at N1 and the other relatively late at P3, allows for the possibility of two separate attentional processes contributing to the hand proximity effect, one more sensory and bottom-up and the other more cognitive and top-down.

To investigate whether hand proximity, without vision of the hand, accentuates the processing of stimuli requiring actions (targets) early (N1) and later (P3) in processing, Reed et al. (2018) used ERP and a similar go/no-go paradigm in which participants viewed stimuli between two panels with hands placed near (hand-near) or far (hand-far) from stimuli. Occlusion of the hand eliminated hand-near target vs. non-target differentiation of the N1; amplification of hand-near target amplitudes emerged at the P3. Visible hand presence appears necessary to draw visual attention to intended-action objects in order to integrate body and visual information early in processing. The integration of visual stimulus information and hand position from proprioception appears later in processing, indicating greater reliance on cognitive systems for discriminating the goal relevance of a stimulus.

Next, Vyas et al. (2019) investigated whether hand function effects previously found in behavioral studies emerged early or later in processing. Using ERPs, they investigated whether hand function influenced the topology of integrated space around the hand. In a visual detection paradigm, target and non-target stimuli appeared equidistantly in front or in back of the hand. Equivalent N1 amplitudes were found for front and back of hand conditions. However, later in processing, P3 target versus non-target amplitude differences were greater for palm conditions. When visual objects appeared in equidistant space around the hand, hand function biases emerged later when targets were selected for potential action. Thus, early hand proximity effects on object processing depend on sensory-reliant neural responses, whereas later multisensory integration depends more on the hand's functional capabilities.

Age-Related Changes in Effector Location and Attention

Finally, an examination of age-related effects on the hand proximity effect reveals the importance of cognitive control in integrating the body with sensory inputs. Little is known about hand proximity effects in older adults (Multhaup et al., 2016). Bloesch et al. (2013) found that younger adults were affected by distractors along the path of a guided reach, whereas older adults were not. This is consistent with attention following the hand in younger adults but not older adults. Multhaup et al. (2016) found that hand proximity increased the size of a remembered area, but it did so equally for younger and older adults. These two findings suggest the possibility of an age-related dissociation. The findings of Bloesch et al. (2013) are consistent with an age difference in earlier, lower level, bottom-up hand proximity effects, whereas the finding of Multhaup et al. (2016) are consistent with age similarities in later, higher level, top-down effects.

The ERP research with young adults reviewed above showed that hand proximity biases attention both early (by the time stimuli are categorized as relevant for action) and later, selectively for goal-relevant stimuli. Reed and colleagues (2017) examined age-related changes in this multisensory integration of vision and proprioception by comparing behavior and ERPs between younger and older adults. In a visual detection task, the hand was placed near or kept far from target and non-target stimuli which were matched for frequency and visual features. Although a behavioral hand proximity effect—faster response times for stimuli appearing near the hand—was found for both age groups, a proportionately larger effect was found for younger adults. ERPs revealed age-related differences in the time course of the hand's effect on visual processing. Younger adults showed selective increases in contralateral occipital N1 and parietal P3 amplitudes for targets near the hand, but older adults showed hand effects only at the P3 and, further, these effects were accompanied by concurrent neural activity in bilateral frontal regions. This neural pattern suggests that compared with younger adults, older adults may produce the behavioral hand proximity effect by integrating hand position and visual inputs relying more on frontal attentional mechanisms and less on early, posterior, multisensory integration.

A formal model of sensory integration by Klatzky and Creswell (2014) provides a framework that may explain why the older adults in our study failed to integrate hand position with visual information early in processing at N1. Klatzky and Creswell propose that each sensory input source results in an estimate for the value of a physical property. The sensory input channels are inherently noisy. Each channel is assigned a weight and integration processes calculate an integrated combination of the input channels which form the basis for future action. In this model, the world varies from moment to moment not only because of changes in the environment but also because of noise in the neural system that makes the detection and correct identification of the visual target more variable (Dematte et al., 2006, 2009; Gottfried & Dolan, 2003). A consistent characteristic of the aging nervous system is greater noise (e.g., Layton, 1975). In the case of hand proximity, the sensory integration process receives two input streams, each noisy. It would not be surprising if the doubly noisy input simply could not be resolved by early sensory integration systems, themselves already noisier, resulting in the absence of the N1 proximity effect in the older adults.

We found an age-related dissociation with the N1 occipital component present in younger adults and absent in older adults, but with the P3 parietal component present in both age groups. This dissociation is consistent with the proposal by Reed et al. (2013) that there are two distinct neural mechanisms underlying hand proximity effects, one early and more sensory and the other later and more task-related and cognitive. Bloesch et al. (2013) found that a visual distractor along the path of a hand movement interfered with the performance of younger adults more than older adults. Interference in older adults was greatest near the body. This result is consistent with an impairment in the early multisensory integration reflected in the N1 component. Multhaup et al. (2016) found equivalent boundary extension in younger and older adults. If boundary extension is a top-down cognitive effect, then the age equivalence would be consistent with the preserved P3 parietal component as well as the enhanced P3 frontal activation. It is possible that the absence of the early N1 component in the older adults may account for the slightly but significantly smaller hand proximity effect in response times.

Although there are issues involved in mapping scalp activity onto underlying cortical activity, these findings are consistent with the posterior-to-anterior shift in activation with age (PASA) that has been described (Davis et al., 2008) and with the compensatory activation of homologous structures in both hemispheres, the compensation-related utilization of neural circuits hypothesis (CRUNCH) of Reuter-Lorenz and Cappell (2008). Together, these results suggest that the early integration of hand position with vision may decline with age, but that later, task-relevant higher level attentional processes (e.g., executive control processes or goal maintenance) may supplement this lack of sensory-related processing, leading to unimpaired behavioral performance. Reuter-Lorenz and Park (2014) propose that phenomena such as this are examples of ***compensatory scaffolding*** that reduces or counteracts the adverse changes in brain structure that occur with age. More specifically, they argue that scaffolding engages supplementary neural circuitry to provide additional computational support required by an aging brain to preserve cognitive function. Thus, the mechanisms by which attention is embodied may change with age as sensory inputs become noisier and less reliably integrated early in processing.

Thus, our ability to perform many of our everyday actions relies on our ability to guide our hands so that they can grasp and interact with objects. Rapid multisensory integration is important in many situations such as slicing bread or vegetables, drinking from a cup, or walking up or down stairs or on uneven ground. The age-related impairment of fast, early mechanisms for integration of information from different senses suggests that older adults may be at a disadvantage in such situations. As a result, it is important to understand the underlying neural mechanisms that allow us to perform these functions and how they change with age.

Effects of Trunk Orientation on Spatial Attention

If embodied attention increases the saliency or activation of regions of space most relevant for performing upcoming actions, then the orientation of the trunk should also influence the deployment of visual attention. The trunk is the structural hub to which our head and limbs are attached and thus, contributes to sensorimotor planning for many typical actions (Darling & Miller, 1995; Guerraz et al., 2006). Typically,

the trunk is aligned with behaviorally important regions of space. When walking we may turn our head and eyes to look in various directions, but we usually move in the direction that the trunk points. Directing attention towards the path of motion allows us to avoid collisions as we move through the environment. Further, aligning the trunk with objects that we intend to manipulate facilitates object interaction because the space immediately in front of the trunk is easily reached with either or both hands. As a result, trunk orientation can indicate behaviorally important regions of space and an attentional bias based on trunk orientation could serve an adaptive function as it could alert us to sudden events occurring in front of us as we temporarily look elsewhere.

Evidence supporting the influence of the trunk on spatial attention can be observed in studies of patients with unilateral neglect. Following brain injury, typically to the right temporoparietal region, patients with neglect fail to attend to and explore contralesional space (Bradshaw & Mattingley, 1995). Several studies have shown that patients with neglect are nevertheless better able to explore and to detect targets in contralesional space when their torsos are rotated toward contralesional space (Karnath et al., 1991, 1993). For example, Karnath and colleagues (1991) observed that hemineglect patients with right-hemisphere brain damage tended to have longer response times to move their eyes to stimuli in the left visual field during covert attention tasks (i.e., saccadic RTs) when their trunks were facing forward. When they rotated patients' trunk midlines to the left so that the visual stimuli were to the right of body midline, difference in saccadic RTs was eliminated.

Further, procedures that induce a displacement of the perceived orientation of the body midline toward the contralesional side can improve patients' neglect symptoms: Cold caloric irrigation of the contralesional ear (pouring cold water into the ear) and warm caloric irrigation of the ipsilesional ear induce vestibular sensations normally associated with body rotation (Rubens, 1985), vibration of the contralesional posterior neck muscles simulates the sensation of the head turning relative to the trunk (Karnath, 1994), and the viewing of a contralesionally moving optokinetic display induce the sensation of the head turning relative to the trunk (Pizzamiglio et al., 1990). For

example, Karnath (1994) found that cold caloric stimulation into the left ear of patients with left hemineglect as well as left-sided neck muscle vibration could reduce the right side bias for patients' perception of "straight ahead." In sum, patients' symptoms improve when the actual or perceived orientation of their trunk is rotated toward the neglected region of space, suggesting that trunk orientation can provide inputs helping to direct damaged attention systems. However, these trunk orientation biases observed in patients with unilateral neglect have also been attributed to a deficit in a body-centered reference frame and to their reduced processing capacity in terms of arousal or attentional demand (Heilman et al., 1978; Hjaltson et al., 1996; Robertson et al., 1995, 1998).

Of interest, is whether these same procedures affect the perception of body midline and distribution of attention in neurologically intact participants (Vallar et al., 1997). Studies of non-brain damaged participants have produced less consistent effects of trunk orientation on attention. Karnath and colleagues did not find equivalent trunk orientation effects in neurologically intact or even in brain-injured controls as in neglect patients for saccadic response times (Karnath et al., 1991), detecting and naming contralesional targets (Karnath et al., 1993), or neck muscle vibration and caloric irrigation in conjunction with tasks known to be sensitive to manipulations of spatial attention (Rorden et al., 2001).

In contrast, other studies using different paradigms have revealed subtle effects of trunk orientation. In a lateralized, target-detection paradigm, Hasselbach-Haitzeg and Reuter-Lorenz (2002) found that participants were slightly faster to respond to targets presented on the right relative to targets presented on the left when their trunks were turned to the right. Further, Grubb and Reed (2002) used a covert orienting paradigm to demonstrate that participants demonstrated neglect-like effects when their trunks were turned to the left: Participants were slightly faster to detect invalidly cued targets on the left and slightly slower to detect invalidly cued targets on the right. Although both of these studies demonstrated effects of trunk orientation, the effects were to different sides and small in effect size. Thus, it is unclear whether the lateralized effects can be attributed to

lateralized brain function, body-centered reference frames, or something specific to the tasks and testing situations.

These mixed findings imply that trunk orientation may provide some input to the distribution of attention, but it may not be strong enough to have an effect unless trunk orientation is relevant to task performance, or the task has sufficient motor and cognitive demands. Understanding these conditions may help us understand when trunk orientation biases occur in undamaged attention systems. For example, the trunk orientation may be more relevant when one is walking, compared to standing still, because it can influence whether one walks into an obstacle. In addition, walking may induce a trunk orientation bias via the introduction of locomotion plus additional motor and cognitive processing demands. In most of the studies that did not find a trunk orientation effect on spatial attention, healthy participants performed a simple attention task while sitting in a static environment. In these cases, trunk orientation was not relevant to the task requirements or the responses and participants could use task-related attention to effectively override any effects of trunk orientation bias.

However, Grubb et al. (2008) did find that the trunk influenced attention when it was relevant to the task. Manipulating trunk and head orientation, they examined visual target detection under different walking conditions that varied task processing demands. In a lateralized visual detection performance task, Hasselbach-Haitzeg and Reuter-Lorenz (2002) compared the influence of trunk orientation on detection time in standing, walking forward, and walking sideways conditions. Trunk bias was observed only in walking conditions, regardless of the perceived direction of motion: faster response times were found to targets in front of the trunk than to ones on the side when participants were walking but not when they were standing. In a subsequent experiment, when cognitive load conditions (i.e., a tone counting task) were pitted against motor conditions load (i.e., walking at an unusual pace) to focus attention to the task via increased cognitive demand or attention to the body via increased physical demands, a trunk orientation effect was only found when motor demands on attention were increased by disrupting automatic walking pace with enforced slower paces. These results suggest that trunk

orientation influences the deployment of attention when the task requires bodily action and places motor demands on processing.

Interaction of Near-Body Attention and Goal-Related Attention

The above research shows a reliable bias for the processing of objects appearing in space near the body to facilitate upcoming or just executed actions, but how strong is this bias? How does the facilitation that occurs close to the body meld with or override the gradients of attention created by instruction or intent or stimulus salience? Mixed findings reported above and a recent criticism regarding the reliability of the hand proximity effect (Dosso & Kingstone, 2018) suggest that this body-related attentional bias is not strong and may be influenced by an observer's goals and expectations.

More specifically, Garza et al. (2013) examined whether the hand's biasing of attention is affected not only by combined visual, tactile, and proprioceptive contributions but also by task expectations. The selection of contending objects by visual attention is a competitive process among sensory-related bottom-up inputs and top-down sources of control to direct attention to particular objects or spatial locations (Kastner & Ungerleider, 2000). Bottom-up neural mechanisms are largely automatic and select on the basis of stimulus features (e.g., luminosity). Multimodal perceptual inputs from visual, proprioceptive, and tactile systems about hand position may act together to increase their salience in the selection process. Top-down mechanisms bias this selection to objects relevant to current behavior and goals. The placement of the hand can bias goal directed behavior because its location and grasping function suggests that a stimulus near it may be important for upcoming action. Thus, a hand positioned in a particular location in the visual field is likely to influence attention from both bottom-up and top-down directions.

In this study, Garza et al. (2013) investigated how changing top-down task priorities alters hand bias during visual processing. Similar to previous studies by Reed and colleagues, this study used a visual covert orienting paradigm with non-predictive cues and had participants hold one hand near the target location on the computer monitor and indicated the detection of the target with a button press

executed by the other hand. Here Garza et al. varied the instructional emphasis to be either on the location of the hand relative to the target or on the location of the hand making the response. When the location of the hand next to the target was emphasized, then response times to targets near the hand were facilitated but when the location of the responding hand was emphasized, then response times to targets near the response were facilitated. This study demonstrated that top-down instructional sets (i.e., what is considered to be most relevant to task performance) can change the processing priority of hand location by influencing the strength of top-down, as compared with bottom-up, inputs competing for attention resources.

How Do Other People's Bodies Influence Attention?

The studies described above emphasize that our own bodies can play an important role in spatial attention. However, attention can also be directed by what other people are doing. Other people's actions provide important sources of information about their intentions, emotional states, and, importantly for us, their future actions (e.g., Loula et al., 2005; Reed et al., 2003). They may also provide cues to the locations of subsequent events and help us plan appropriate reactions to those events. To humans, objects in peripersonal space are important not only because you may grasp them but also because they may grasp you.

Other people's hands direct our attention through pointing and gesturing and often create a joint focus of attention. One question is whether viewing the actions of another's hands biases an observer's processing of space near the other person's hands. Embodied simulation theory (Wood et al., 2016) suggests that when one views an action displayed by another, the viewer's ability to recognize, understand, and respond to the action is based on a sensory-motor simulation of the observed action. In other words, the observed action is simulated by the observer's own brain, which leads to activation in other brain regions associated with the observed expression. To investigate whether the hands of a co-actor could bias an observer's attention to nearby stimuli, Sun and Thomas (2013) modified the

covert orienting task and asked participants to place either their own hand or a friend's hand next to one of the target locations. Despite showing faster detection for objects appearing near participants' own hands, no such facilitation was found for targets appearing near the friend's hand. However, after participants and their friend performed a "joint action" training task (each holding the end of a wire to cut through a wax block) prior to the experimental task, biased visual processing was found near the friend's hand. Sun and Thomas argue that the joint action task created a joint body schema, allowing the participants to incorporate friends' hands into their own body schema, thus making the task and the space near the friend's hands relevant to their joint goal.

In addition to shared actions performed by the hands, the directional information from gaze, head turning, and pointing in others may be critical for attention shifts. Gazing is one type of action we can observe in others. In typical studies of spatial attention and gaze direction, participants viewed a face in which the eyes looked to the left or right; participants responded faster to targets consistent with gaze direction (Friesen & Kingstone, 1998; Kingstone et al., 2004). In addition, other types of actions may be socially relevant for directing attention toward some future event of interest. For example, Langton and Bruce (2000) examined whether pointing cues direct attention. In a covert attention paradigm, central cues of a person pointing with his hand were presented; participants responded more quickly to targets corresponding with the pointed direction. Nonetheless, not all body postures direct attention. When left and right-facing heads and trunks were used as cues, head cues shifted attention, but trunks did not (Heitanen, 2002). These studies suggest that attention is directed by bodies in action that contain directional information about impending changes in the environment and our need to respond to it, but little work has addressed this issue.

To investigate how the actions of others direct attention, Gervais et al. (2010) and colleagues compared different types of actions in a covert-orienting task with non-predictive central cues. The cues were static images of human figures in mid-action (e.g., throwing or running) or standing in a neutral, hands-at-sides pose. They either faced to the left or the right of the screen. Results indicated that only

action cues produced validity effects, that is, relatively faster responses to targets appearing on the side consistent with the direction of the action. Attention appeared to be shifted in the direction of the implied action. Further, the action cues produced the faster responses than the standing cues, implying that action cues may have primed motor responses.

Spatial Attention and Future-Oriented Behavior

Spatial attention plays an important role for performing functional actions in the environment, but selective attention is also important for preparing for upcoming action as well. In fact, in the real-time flow of natural behavior, we attend to relevant regions for current action while at the same time planning a sequence of future actions. By prioritizing activation based on both bottom-up and top-down inputs, attention should be critical to such preparation. Action sequences cannot be mostly reactive to changes in environmental features because responses will often be too late—some form of prospective control is necessary. Alternatively, action sequences cannot be planned too far in advance since not all relevant contextual information for planning action can be known in advance. Thus, selective attention processes help the performer to determine what information is most relevant at different points in time during a flow of action (e.g., Roberts & Ondrejko, 1994). It is an integral part of the continual perception-action cycle with the goals of action influencing perceptual selection and information gleaned from the environment influencing subsequent planning for action (Neisser, 1976).

The research described in the preceding sections examines spatial attention at specific moments but does not capture the dynamic cycling between perception and action that is characteristic of real-world performance. Bryan and Harter (1899) were some of the first researchers to recognize the role of prospective control in skilled performance. They studied telegraph operators and found that as operators became increasingly skilled, they used predictable patterns in word and phrase structures to more efficiently organize on-going actions. Later, researchers recognized that in order for behavior to be

effective and fluid, action must be based on anticipated future states of the environment and of the self (Lashley, 1954; Miller et al., 1960).

Work examining the coordination of eye movements and actions provided some insight into this issue. Johansson et al. (2001) studied eye-hand coordination in a simple task involving picking up an object and moving it to a target location while avoiding an intermediate obstacle. They found that gaze moved from a landmark to the next landmark just as the hand reached the first landmark, anticipating the next portion of the movement. For example, gaze left the area of the obstacle just as the object was about to clear the obstacle and moved to the final target location. Hayhoe et al. (2012) found that, in real-world games of squash, players moved their gaze to a spot on the front wall approximately where the opponent's shot would hit, and did so just as the ball left the opponent's racquet. Diaz et al. (2013) confirmed this in a virtual reality task resembling squash or racketball. Participants, whose task was to make contact with an approaching ball, moved their gaze with high accuracy to the location where the ball would be 160–170 ms after a bounce, and did so before the ball bounced. Interestingly, they accurately adjusted the shift in response to changes in the elasticity (bounciness) of the ball.

To consider more specifically how skilled actors utilize perceptual selection to anticipate future states and plan upcoming action accordingly, Roberts and Ondrejko (1994) used an especially designed video game in which they simultaneously recorded task actions and eye movements while participants played the game. Players controlled the orientation of a ship that could shoot at multiple moving targets. The goal was to hit as many targets as possible and not allow the targets to intercept the ship. At any point in time the screen contained many moving objects, some of which were better targets than others, depending on their trajectories, velocities, and upcoming locations relative to the ship. Thus, the game, as in many everyday contexts, presented the actor with a cluttered environment where some locations provide more information than others, depending on one's current and upcoming goals and actions. In the game, finding the next target among many possibilities, determining the current orientation of the ship, moving the ship to a new orientation, and deciding when to release the shot to time an interception successfully, all required

different kinds of information that were available at different locations. Thus, there was inherent competition about where to look when, because of the variety of visual stimuli and by the mix of the flow of task goals and specific situations the game presented at any one point in time (e.g., the sudden appearance of a fast moving obstacle coming toward the ship).

The above findings revealed tight correspondences between current and upcoming task actions and the timing and location of players' eye movements. Players precisely relocated their foveas to areas of the screen that monitored on-going activity, but more interestingly, to locations that provided detailed spatial or location information that was relevant for guiding specific upcoming actions. For example, performers were able to shift between looking at the target and looking at the ship when setting up for the next shot. Players did not foveate on more than one or two potential targets even when there were many possibilities. Players used peripheral information to make the selection of the new target and usually made a saccade to the new target less than 1 s after the previous target was shot. Analyses of the trajectories and future locations of all possible targets indicated that performers most often looked at the one or two "best" possible targets in terms of the ease of making an intercept and/or likelihood of an eventual crash with the ship. Remarkably, peripheral selection must have occurred in many cases well before the previous shot even reached the target. Selective attention, then, biased visual information gathering that was then was used to regulate ongoing action and prepare for upcoming action. Selective attention occurred in the service of the players' goals, but was also constrained by particulars of the changing visual landscape of the game.

This work emphasizes the role of selective attention in perception-action cycling and fits well with the biased competition model of Desimone and colleagues (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000). Multiple potential targets in the world compete for resources that result in specific action selection. In the video game, action selection occurred in terms of eye movement to specific targets and subsequent finger responses to control the ship. This type of real-time research examining selection and action sequences for future-

oriented actions should provide additional insight into the body's role in selective attention.

A Model of Embodied Attention: Integrating Inputs from the Body, the Environment, and Goals

Attention is the construct used to explain the effects of a continuously updated prediction about what will happen next in the environment and how our body will need to react as well as a continuously updated monitoring of what we want to happen next and how our body can accomplish it. Our bodies influence attention both by the location of an effector (such as the hand) in space and also by the functional range of the effector's actions. Even without action, body-part location prioritizes space by speeding responses to targets appearing in the functional range of the effector. When actions are performed by an effector (i.e., the hand) they too can change the allocation of attention to the functional range of the action. Thus, the topography of spatial attention appears to be defined by body part location, but action changes its dynamics. Superimposed on this, our goals and intentions change the allocation of attention.

The difference between the effects of hand presence and hand action on spatial attention and the effects of task relevant mechanisms may reflect contributions from different neural networks to visuospatial processing. ERP research has helped to clarify the timing of the multisensory integration process and the role of action in the facilitation of processing. It has also clarified how the embodiment of attentional mechanisms can change as sensory systems age. When perceptual inputs become less reliable—either from declining sensory function or attentional activation—goal-related attention overrides the perceptual predisposition. Although this can produce mixed results on the finding of embodied attention, it is also adaptive. Interacting with a dynamic environment, using our effectors is not obligatory. We do not have to grab things near our hands or bodies. For example, just because our hand is near a beehive does not mean we want to grab it!

Instead, we want our goals to take precedence in determining upcoming functional action.

Thus, we propose a dynamic model of embodied attention that modifies the biased competition model proposed by Desimone and colleagues (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000). In this model (Fig. 12.2), our neural systems integrate activation from sensorimotor regions to create an attentional bias or predisposition to increase the saliency of functional space near our effectors. The locations of these neurons create an integrated neural network to facilitate potential action. This processing bias can be amplified when action in this area is relevant or can be inhibited when action elsewhere is needed. Multisensory inputs can be integrated with motor intentions to direct attentional resources from current actions to areas relevant for sequential actions. Finally, these lower level biases can be overridden when action representations and body representations combine to anticipate action and when goals and intentions indicate that spatial attention is relevant in other regions. As shown in Fig. 12.2, these body-related processes, action-related processes and goal-related processes compete simultaneously for resources and what we measure in terms of behavior or outcomes is the product of the relative strength of these various inputs. This type of dynamic, competitive system allows us to be predisposed for action, but with the ability to adapt to environmental changes and our own changing goals.

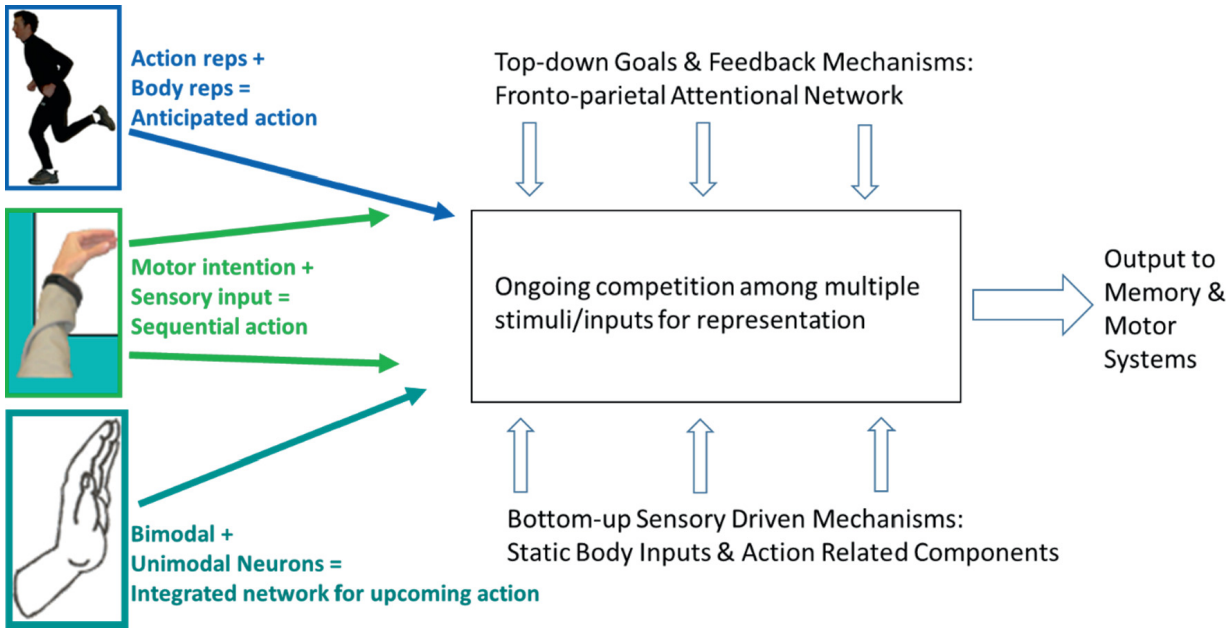


Fig. 12.2 Modified biased competition model indicating how inputs from multiple levels can influence the competition of processing resources affecting action. Bimodal and unimodal neuron activation create an integrated neural network for upcoming action. Motor intentions and sensory inputs direct the focus of attention for sequential action. Action and body representations (reps = representations) are combined to direct attention for anticipated action

Conclusions

Every day we perform actions in the world. These actions produce changes in our environment and allow us to respond to changes initiated by others. Our bodies, our actions, and the actions of others all influence the dynamic distribution of spatial attention. Attention is not merely a visual phenomenon. Its effects appear to be related to the body's capacity for performing functional actions. Thus, it makes sense that the allocation of attention results from the integration of information across these levels and that it serves the successful implementation of action.

Given that most tasks involve our body and lead to physical output, our actions have implications for other people and vice versa. Thus, any theory of spatial attention is incomplete if it does not emphasize the importance of sensorimotor experience and the interaction of the body with the world. Spatial attention is a dynamic system that is influenced by our own bodies and actions and our future actions. In conclusion, an embodied theory of spatial attention accounts for the

ever-changing influences from the body and its actions that produce functional interactions with the world.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_13

13. The Role of Motor Action in Long-Term Memory for Objects

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Abstract
Motor actions associated with grasping or using objects are part of object knowledge and may be automatically activated during object perception. Such findings suggest that the motor system has a supporting role in object representations. We investigated the role of motor actions in long-term memory for objects. Results from the few available studies suggest that attention to motor actions is necessary in order to find support for the role of motor actions. We performed an experiment using a neutral study instruction in which participants studied manipulable and nonmanipulable objects followed by free recall. The results showed no evidence that memory for manipulable objects was affected more by motor interference than memory for nonmanipulable objects. Thus, our results do not support the view that the motor system plays an important role in object memory. Rather, these results fit with the view that object representations are flexible and contain motor features only when they are relevant. We conclude that the motor system is not necessary to represent objects and question whether it is relevant at all for abstract concepts.

Keywords Long-term memory – Motor action – Motor interference – Affordances – Grounded cognition

We thank Elena Bartke, Femke Stolte, Mitchell van Vugt, and Jessica Keijzer for their help with pilot studies and this experiment.

One of the central ideas in the grounded cognition framework is that of sensory-motor simulation (Barsalou, 1999, 2008). According to this view, in order to meaningfully represent a concept, we run a mental simulation of the perceptions, actions, and interoceptions that would also be activated in an actual experience with the concept. Thus, representing the concept ***banana*** could consist of a mental simulation of seeing, grasping, peeling, biting, smelling, and tasting a banana. These simulations give concepts meaning and support actions (Glenberg, 1997; Meyer & Damasio, 2009).

The Role of the Motor System for Concepts

In this view, a special role has been proposed for the motor system in memory for objects (see Iani, 2019, for a recent discussion). Downing-Doucet and Guérard (2014) argued that object retention processes recruit the motor system and suggested that object memory might be a "by-product" of the interactions between perception and action. Glenberg (1997) has argued that the main function of memory is to support actions and that concepts are the "meshed" affordances of current and past experiences. In other words, perception of an object leads to the conceptualization of a mixture of current affordances and actions performed in the past. On this account, the motor system is necessary for concepts. Lagacé and Guérard (2015) further argued that the affordances that are activated either by a visually presented object or by object knowledge are recruited to retain objects in memory. In support of this idea, studies have shown that motor actions are activated by pictures or names of manipulable objects (Chua et al., 2018; Rueschemeyer et al., 2010; Till et al., 2014). Yet, not all findings seem to support this idea that sensory-motor simulations are central to concepts (e.g., Papesh, 2015; Petrova et al., 2018). In this chapter, we

will investigate the role of motor simulations in object memory, in particular whether motor simulations support object memory.

Memory for actual actions is affected by concurrent motor actions, suggesting that action representations in memory and real performed actions at least partly rely on the same mechanisms (but see Helstrup, 2001). For example, Smyth and Pendleton (1989) found that recall of a series of movements was reduced when participants performed a conflicting movement task (squeezing a foam tube) compared to a spatial task (tapping a pattern with a hand) even if the interference hand and the hand used during recall were different. An opposite pattern of interference was obtained in the Corsi blocks spatial span task, indicating that the conflicting movement task was not overall more interfering than the spatial task. The effect of interference on memory for motor actions thus depends on the nature of the interfering task. For example, ***spatial*** aspects of rowing were disrupted more by a spatial short-term memory load than by a body configuration memory load, while the ***configuration*** aspects of rowing showed the opposite pattern (Woodin & Heil, 1996), and short-term memory for ballet moves was decreased by a concurrent arm movement task but not by visual interference (Rossi-Arnaud et al., 2004).

If motor simulations are an important part of an object's representation, as has been argued by proponents of grounded cognition, it follows that memory for objects should show similarities to memory for actions. Thus, we reasoned that object memory should also be reduced by a concurrent motor task. However, studies investigating memory for object pictures or object names do not consistently find a role of motor actions (Pecher, 2018; Pecher & Zeelenberg, 2018; Zeelenberg & Pecher, 2016). These mixed findings suggest that motor actions may not be necessary for object representation (Fischer & Zwaan, 2008), but rather result from spreading activation after the core meaning of the concept has been accessed (Mahon & Caramazza, 2008). Indeed, such criticism seems warranted by the sometimes rather vague description of how sensory-motor processing and concepts are "interconnected," "associated," or engage in "cross-talk." Some results that are taken to indicate a supporting role of motor actions might indeed also be explained by

spreading activation as a result of representing an object rather than supporting it. For example, Glenberg and Kashak (2002) observed that after reading a sentence such as ***close the drawer,*** participants are faster to respond with a movement that is congruent with the direction implied by the sentence (e.g., away from the body) than a movement that is incongruent. Scorolli and Borghi (2007) found that action sentences facilitated response actions made by the same effector (mouth, foot) as the one implied by the action verb in the sentence. Although this finding could be interpreted as showing that the action was activated as part of understanding the sentence and thus could be necessary for representing its meaning, the alternative explanation is that the action was activated only after the sentence was completely understood and therefore not essential in the language comprehension process.

Neuro-imaging studies show that motor areas are activated by manipulable objects (Chao & Martin, 2000; Grezes & Decety, 2002) even when affordances are task irrelevant (Proverbio et al., 2011) and when stimuli are words (Rueschemeyer et al., 2009). These results could also be the result of spreading activation. Handy et al. (2006) found that activity in motor areas was obtained mostly when participants viewed objects (rock climbing holds) that they did not have experience with, so this puts into question whether activity in motor areas even indicates motor knowledge. Moreover, in a meta-analysis of imaging studies, Watson et al. (2013) found that action pictures or words did not show consistent activation in motor areas, which further calls into question the idea that motor knowledge is central to concepts (see also Postle et al., 2008).

Is Motor Knowledge Necessary for Concepts?

We argue that the idea of sensory-motor simulations requires a more stringent test where it is shown that concepts suffer when sensory-motor processing is compromised (Mahon, 2015), for example, because participants are performing a secondary interfering task that engages the same processes (Pecher, 2013; see also Helstrup, 2001). Although some studies have shown interference (Witt et al., 2010; Yee et al., 2013), these results might be due to spatial attention rather than

interference of the motor system (Matheson et al., 2014). Strozyk et al., (2019, also see Miller et al., 2018) found that lexical decisions to hand- and foot-related words were faster if the response had to be made with the relevant effector (hand or foot), but that hand or foot interference did not have different effects on responding to hand- or foot-related words. They concluded that participants reactivated experiential traces linked to specific effectors, but that this reactivation was not functional to lexical processing.

The role of motor actions in short-term memory for objects has also been investigated with motor interference paradigms. A few experiments have shown memory effects of similarity in how objects are interacted with and have also shown that these effects disappear with motor interference (Downing-Doucet & Guérard, 2014; Guérard & Lagacé, 2014). In contrast, we have repeatedly failed to find selective interference effects in short-term memory. Pecher (2013) studied short-term memory for manipulable and nonmanipulable objects. If motor information is activated and contributes to memory performance, interfering with such activation should be more detrimental for objects that are often manipulated (e.g., ***hammer***) than for objects that are not (e.g., ***chimney***). Contrary to this prediction, however, no such evidence was found (Pecher, 2013; Pecher et al., 2013; Quak et al., 2014).

Concepts Are Flexible

Another reason that results are mixed might be that sensory-motor simulations are flexible, and their nature depends on the task and other contextual factors (Barsalou, 2016; Lebois et al., 2015). Concept features vary in accessibility (Barsalou, 1993) such that the inclusion of a particular feature in a concept representation depends on the current task context (Barsalou, 1982; Conrad, 1978; Meteyard et al., 2012; Tabossi, 1988) and by other recent contexts (e.g., Pecher et al., 1998). For example, in Pecher et al. (2007), participants verified a visual property (***chocolate is brown***) or a non-visual property (***chocolate is sweet***) for a concept. Later, they were shown grey-scale pictures of concepts in a recognition memory task. Memory performance was better for concepts that had been presented with a

visual property than for concepts that had been presented with a non-visual property, even though the property was not shown in the picture. The explanation for this difference is that on the first presentation, participants were more likely to run a visual simulation of the concept if the property was visual than if it was non-visual, and that the picture in the recognition test was a better match for the previous visual simulation than the non-visual simulation.

Lebois et al. (2015) even argue that concepts have no core meanings that are activated whenever the concept is processed. Instead, they propose that all features of a concept are context-dependent and their accessibility varies dynamically according to context. That effects that would be predicted by grounded cognition theories do not always occur does not necessarily mean that the concept is amodal. It just means that only features that are relevant in the task context are active. It would probably prove hard to derive strong predictions that distinguish between this account and a spreading activation type account (Mahon & Caramazza, 2008). According to the spreading activation account, sensory-motor information may be activated when a stimulus is presented but it is not an essential part of conceptual processing. On the context-dependent activation account of Lebois et al., sensory-motor information is an essential part of conceptual processing but the features that are needed to constitute a concept will vary according to task demands. It seems that both accounts are flexible enough to explain a wide variety of results.

Manipulable objects may activate different kinds of information. Objects may activate volumetric information (how they can be grasped) if they are presented as pictures, because the shape information is directly available in the visual input, whereas this may be less so for object names. Actions activated by object names might be more related to their function than their shape (Matheson et al., 2018). The degree to which object-related actions are activated may also depend on the actions needed to perform the task (Bub & Masson, 2010; Bub et al., 2008), and different types of actions might be activated at different points in the time course of processing the object (Bub et al., 2018). Task instructions play an important role (Thomas et al., 2019; Yu et al., 2014). Sentence context influences the availability of

motor actions (Borghi & Riggio, 2009; see also Dutriaux et al., 2019; Taylor et al., 2008), although Borghi and Riggio (2009) found that motor actions were available even when they were irrelevant in the sentence context, but when the sentence context made actions relevant they were more clearly defined. Osiurak and Badets (2016) argue against automatic activation of motor actions for objects, but instead argue that motor actions can be activated as a result of a reasoning process. Papeo et al. (Papeo et al., 2009) similarly concluded from a TMS (Transcranial Magnetic Stimulation) study that any activity observed in the motor cortex for action-related words is due to strategic rather than automatic processing. They observed effects only late in processing of a word, and only when the task required participants to make semantic judgments related to action.

The Role of Motor Knowledge in Short-Term Memory

This flexibility in activation of motor features might explain why some studies have found that motor features have an effect in short-term memory (Zeelenberg & Pecher, 2016). Downing-Doucet and Guérard (2014) studied the effect of motor similarity on short-term memory for object pictures. Participants studied six objects in which each were associated with two grips. Before each object, a short video was shown of a hand performing one of the two grips. In the similar condition, the same grip was shown before each object on the list, whereas in the dissimilar condition, different grips were shown. Downing-Doucet and Guérard (2014) found that short-term memory for the order of the objects was better for the dissimilar condition than for the similar condition. Thus, memory performance for the same set of six objects was influenced by the variability of the videos shown before each object. In our view, the most likely explanation for this finding is that the videos were used as cues during memory retrieval, and caused more interference in the similar than in the dissimilar condition. If, however, the effect was due to similarity in the object representations themselves, it seems unlikely that these effects show that actions are a necessary part of the object representations, because which action was represented depended on the context.

In a similar short-term memory task, Lagacé and Guérard (2015) manipulated the congruency of actions with to-be-remembered objects. Participants observed an action video that was congruent or incongruent with the object picture that followed. They were instructed to copy the grasp and memorize the order in which objects were shown. Memory was better in the congruent trials than in the incongruent trials. Lagacé and Guérard (2015) argue that the transitions between motor actions support order information. It is surprising, however, that object-action congruency would support memory for order but not for the objects themselves (Quak et al., 2014).

Helstrup (2001, see also Iani, 2019; Lagacé & Guérard, 2015; Zeelenberg & Pecher, 2016) proposed that different strategies can be used to memorize action information, depending on the availability of information. Actions may be encoded as motor programs, as visual patterns, or as verbal codes. If interference during encoding is motoric, participants may encode movements visually or verbally. Moreover, Helstrup (2001) observed larger effects of verbal and visual interference than of motor interference, suggesting that participants are even more likely to encode actions verbally or visually than motorically.

In sum, studies on short-term memory for objects and words have occasionally provided evidence consistent with the view that motor actions contribute to memory performance, but the evidence supporting this view has been far from consistent. Moreover, in studies that provided evidence for motor involvement, the method seemed to emphasize motor actions. A possible explanation for the minimal role of the motor system is that short-term memory depends to a large extent on surface characteristics of the stimuli (e.g., Baddeley, 1986, 2003; Mazuryk & Lockhart, 1974; Rose et al., 2010), which are, in the case of object pictures, mostly visual. In contrast to short-term memory, long-term memory clearly relies largely on conceptual knowledge (e.g., Barclay et al., 1974; Craik & Lockhart, 1972; Deese, 1959; Shiffrin et al., 1995; Zeelenberg et al., 2003). Under the assumption that motor knowledge is an important part of concepts, long-term memory might therefore show a more robust contribution of motor actions to memory performance.

The Role of Motor Knowledge in Long-Term Memory

Only a few studies have examined the role of motor actions in long-term memory for object pictures and names. Ross et al. (2007) tested participants in a category learning task, in which they performed arbitrary response actions to categorize novel geometrical objects. Subsequent old/new recognition performance was affected by the overlap in response actions; responses were faster and more accurate for objects that required the same motor action during study and test than for those that required different motor actions. These results suggest that actions encoded during study might work as a contextual cue during retrieval (see also Dijkstra et al., 2007), similar to other types of context reinstatement (e.g., Light & Carter-Sobell, 1970; Tulving & Thomson, 1973). In that case, the motor action may not be central to the concept but rather to the specific study episode.

Results from other studies suggest that motor actions actually contribute to memory for objects. Verbally learning the function of new objects was hindered by a concurrent manual-interference task (Paulus et al., 2009). Unfortunately, Paulus et al. (2009) did not present a control condition in which they tested the effect of motor interference on learning of nonmotor features of new objects, so it is unclear whether the interference task harmed the function information specifically or was interfering with attention in general. Rather than interference, Matheson et al. (2019) found facilitation due to a concurrent motor task. Participants learned names and functions of novel tools. During a final recognition (studied vs nonstudied), test participants performed a secondary unrelated motor task during half of the recognition blocks. The difference between RTs for studied and nonstudied object names was larger during interference blocks for participants who had learned the function of objects by manipulating the objects themselves, but was larger during no-interference blocks for participants who learned the function by observing the experimenter's action and verbally describing the function. Thus, Matheson et al. (2019) found state-dependent learning. The effect of interference was facilitatory, which contrasts with other findings.

Representations of novel objects strongly depend on the particular study episode, which might focus explicitly on motor actions, and thus result in representations in which motor actions are relatively more important. A stronger test of the role of motor actions in object representations might be long-term memory for familiar rather than novel objects. Here also the few results are mixed. Memory for pictures of manipulable objects was worse when participants adopt a posture that prevents hand actions (Dutriaux & Gyselinck, 2016), suggesting, according to the authors, that motor simulations contributed to object memory. In contrast, Canits et al. (2018) found no effect on long-term memory for objects when the study task involved compatible or incompatible grasping responses, even though grasp compatibility did affect response times during study. Moreover, (Guérard et al., 2015) found that motor interference did not systematically affect long-term memory performance for objects even though it did affect short-term memory performance. This is puzzling, because long-term memory is generally thought to rely more on conceptual processing than short-term memory.

These studies with familiar objects all manipulated motor actions during encoding, which may have motivated participants to focus especially on motor features or away from them, depending on whether the motor actions were congruent or interfering. To our knowledge, only one long-term memory study manipulated actions after initial learning (i.e., during the retention interval). Van Dam et al. (2013) studied memory for lists of object names that would require a pressing (e.g., ***piano, doorbell***) or twisting (e.g., ***screw driver, pepper mill***) action when interacted with. During the retention interval, participants performed an ostensibly unrelated number decision task in which they had to respond by either pressing or twisting a response button. In the final recognition task, memory for object names that were congruent with the action performed in the intervening unrelated task was better than memory for object names incongruent with the actions performed during the intervening task.

In the present study, we investigated the role of motor actions in long-term memory for objects. Specifically, we investigated whether motor actions are encoded in object memories under conditions that do not explicitly focus on motor actions. Given the important role of

action in the grounded cognition framework, we expected that something as fundamental to cognition as long-term memory should be supported by the motor system. As described, only a few previous studies have addressed this topic, and only the study by Van Dam et al. (2013) could be considered evidence for the spontaneous encoding of motor features.

Neuro-imaging studies have shown larger responses of motor-related brain areas to manipulable than to nonmanipulable objects (Chao & Martin, 2000; Chao et al., 1999; Martin, 2007; Rueschemeyer et al., 2009). These observations suggest that the motor system may be involved in the representation of manipulable objects, more so than in the representation of nonmanipulable objects. In the experiment reported here, we compared the effect of motor interference during recall on memory for manipulable and nonmanipulable objects. Using this comparison, we can distinguish between a specific effect of interfering with the motor system and a more general attentional effect of performing a concurrent task, similar to our previous short-term memory studies (Pecher, 2013; Pecher et al., 2013; Quak et al., 2014).

The motor system might be involved during memory encoding or memory retrieval or, most likely, both. During encoding, motor information that is activated as part of the object identification process will be encoded in the memory trace for the object. Given the flexibility of representations, however, motor interference would prevent the encoding of motor information, resulting in representations that rely more on other, probably visual, features. During retrieval, motor interference will prevent the use of actions as cues, and it will prevent activation of the motor information that was stored during encoding, resulting in poorer recall for objects that have associated motor actions (see Iani, 2019, for a similar argument). Therefore, we used motor interference only during memory retrieval, so that there would be optimal opportunity to activate motor information during study. If motor information is an important part of the representation of a manipulable object, a neutral instruction to study the objects for a later memory test should result in the spontaneous activation of motor features for manipulable but not for nonmanipulable objects. Motor interference during retrieval should

then have a larger detrimental effect on memory for manipulable than nonmanipulable objects.

Experiment

Participants

Forty-eight students at the Erasmus University Rotterdam participated for course credit. The mean age was 20.8 years (range 17–55), and 45 were female. We sampled participants sequentially using a stopping rule based on the outcome of a Bayesian test (Schönbrodt et al., 2017). Therefore, we calculated the JZS Bayes Factor (***BF***) for the interaction. The Bayes Factor is the ratio of $\boldsymbol{p}(D \mid H_0)$, the probability of observing the data under the null hypothesis, and $\boldsymbol{p}(D \mid H_1)$, the probability of observing the data under the alternative hypothesis (Rouder et al., 2009). Using the JASP software (JASP Team, 2017), we performed a one-sided ***t***-test with a scale parameter of $\boldsymbol{r} = 1$ (Schönbrodt et al., 2017). The one-sided Bayesian ***t***-test tests whether the effect of motor interference on recall (i.e., the difference in recall between the motor-interference condition and the control condition) is larger for manipulable objects than for nonmanipulable objects. Our threshold for stopping was a Bayes Factor of 10 in favor of the null hypothesis or a Bayes Factor of 10 in favor of the alternative hypothesis. As planned, an initial sample of 40 participants were tested and the Bayes Factor for the data of these 40 participants was computed. The resulting Bayes Factor was below 10. As per our preregistration, we increased the sample size in steps of eight participants (because the experiment had eight counterbalanced versions). After one step increase (i.e., when we tested the data for 48 participants), the threshold was reached. Our sampling plan was preregistered at https://osf.io/e3q4t/registrations.

Materials

The study items consisted of a set of 128 color photographs of common objects (e.g., tools, animals, buildings, signs) against a white background (available from https://osf.io/2hkb7/files). These stimuli were taken from a larger set of pictures for which we collected manipulability and frequency ratings on a seven-point scale (32–35

ratings per picture) in a previous pilot study (also used in Pecher, 2013; Pecher et al., 2013; and Quak et al., 2014). In the resulting set, 64 pictures were rated as high manipulable (***M*** = 5.34, range = 5.00–6.59) and 64 as low manipulable (***M*** = 2.02, range = 1.21–3.06). The items were matched on rated subjective frequency (***M*** = 3.89, range = 1.33–6.91, and ***M*** = 3.50, range = 1.56–6.54, for manipulable and nonmanipulable items, respectively). The pictures were divided into four sets of 32 pictures, each containing 16 manipulable and 16 nonmanipulable items. For the filler task, 200 multiplication problems were created. A metronome was used to play the beats that indicated the speed of finger movements. A video camera was used to record whether the participant followed the interference task instructions correctly. Participants who did not follow instructions were replaced.

Procedure

The experiment consisted of four study-test blocks. Each block consisted of a study phase, a 2-min filler task, and a test phase. In two of the four blocks, participants performed a motor-interference task during the recall phase. In the two other blocks (i.e., the control condition), participants performed no secondary task during recall. The motor-interference task consisted of sequentially touching the thumb to the index finger, pinky finger, middle finger, and ring finger of the same hand, performed with both hands. This sequence was repeated throughout the recall phase to the beat of the metronome set at 92 beats per minute. Before the start of the first block, the experimenter explained the motor-interference task and demonstrated the hand movement. The participant performed the task until the experimenter was satisfied that the participant had understood it. For counterbalancing purposes, the motor-interference task was performed during the recall phases of blocks 1 and 4 for half of the participants and blocks 2 and 3 for the other half.

During each study phase, 16 manipulable and 16 nonmanipulable objects were presented in random order. New random orders were generated for each participant. Each picture was presented for 2000 ms, followed by a 500 ms blank screen. Participants were instructed to study the pictures for a later memory test. In the 2-min filler intervals between the study and test phases, participants solved

multiplication problems. At the start of the test phase, participants were asked to recall as many of the objects as possible from the preceding study phase during a 2-min retrieval period by naming or describing the objects out loud in any order.

The entire experiment took around 30 min. Participants were tested individually, with an experimenter present during the entire experiment. The experimenter monitored if participants were following instructions correctly during the recall task. In addition, participants were videotaped to check their compliance with instructions. The four picture sets and order of interference and control blocks were counterbalanced in eight versions such that, across participants, each set of pictures occurred equally often in every block, with and without a concurrent motor-interference task (Zeelenberg & Pecher, 2015). After completion of the experiment, participants were asked to provide their gender and age information. After participants' compliance with instructions was verified, their videos were deleted.

Results

The proportion of correctly recalled objects for each condition was computed and is shown in Fig. 13.1. The effect of motor interference did not differ between manipulable and nonmanipulable objects. For the Bayesian analysis, the difference between recall with and without motor interference was computed for the manipulable and nonmanipulable objects separately. A one-sided Bayesian ***t***-test comparing these differences between manipulable and nonmanipulable objects showed a $BF_{01} = 10.60$. Thus, the data provide strong evidence for the absence of an interaction. This result shows that the effect of motor interference did not differ between manipulable and nonmanipulable objects. Another one-sided Bayesian ***t***-test showed that motor interference did reduce recall performance, $BF_{10} = 154.86$. This main effect of interference likely shows that the interference task required attention, and therefore distracted participants from the recall task. Because the main effect of manipulability was not relevant to our question, we did not analyze it. It appears that there is an advantage for nonmanipulable objects, consistent with previous studies (Guérard & Lagacé, 2014; Pecher, 2013). The manipulable and nonmanipulable objects were matched on

familiarity, but there may have been other aspects on which they differed, such as relatedness or similarity between items. The data are available at https://osf.io/2hkb7/files.

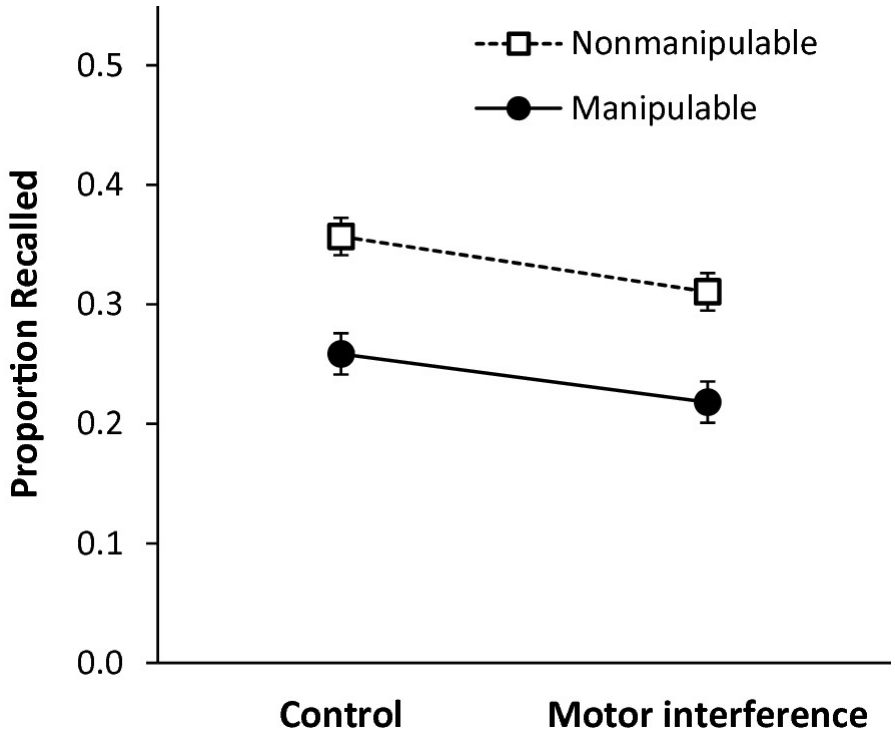


Fig. 13.1 Mean proportion correctly recalled pictures. The error bars indicate standard error of the mean interference effect for each type of object separately

Discussion

We investigated the effect of motor interference on memory for object pictures. We did not obtain evidence that motor interference had a larger effect on memory for manipulable than nonmanipulable objects. Thus, our results do not support the idea that motor actions play a necessary role in long-term memory for objects.

One objection to this conclusion might be that the motor-interference task might not have interfered with the activation of motor actions associated with the objects presented for study. Previous studies have shown, however, that similar motor-interference tasks interfere with episodic memory for actual actions (e.g., Woodin & Heil, 1996), with judgments about how objects are usually grasped (Pecher, 2013), and with short-term memory for action words (Shebani

& Pulvermuller, 2013). The selective nature of motor-interference effects in these experiments, such as the limb-specific interference obtained by Shebani and Pulvermuller (2013), indicates that these effects were not due to a general decrease in processing resources. The results of many studies have been taken to imply that the actions associated with manipulable objects are automatically activated when people perceive a picture of an object or object name (Bub et al., 2008; Glover et al., 2004; Tucker & Ellis, 2004). If these afforded actions are automatically activated and encoded in memory, one would expect these to support later memory for objects. Thus, we expected that the motor-interference tasks would have a detrimental effect on memory for manipulable objects.

Flexible Use of Motor Knowledge

Our results suggest that motor actions do not support memory for objects when access to motor knowledge is not required by the memory task. Although requiring participants to use motor-related information during encoding might induce an effect of motor interference, and may explain some of the results in short-term memory studies, our results indicate that the motor system is not spontaneously recruited during encoding. Note that, in principle, recall of pictures could be based entirely on visual representations, yet hundreds of memory studies have shown that participants use semantic knowledge when recalling or recognizing previously presented stimuli (e.g., Barclay et al., 1974; Craik & Lockhart, 1972; Deese, 1959; Light & Carter-Sobell, 1970; Roediger & McDermott, 1995; Shiffrin, et al., 1995; Zeelenberg et al., 2003). If people use information associated with but not present in the stimuli themselves, such as phonological or semantic information, then this raises the question of whether this is also true for other kinds of information, such as the actions associated with stimuli.

Because in the grounded cognition view, action-related information is assumed to be activated automatically and to form a crucial part of conceptual knowledge, we reasoned that motor information would play a role in memory for objects. Precisely, this reasoning was used by researchers who did obtain evidence for the idea that motor actions

support memory for objects and action-related words in recall and recognition tasks that like ours did not require access to motor knowledge (, Shebani & Pulvermüller, 2013; van Dam et al., 2013). As we discussed in the Introduction, however, most of the studies that did obtain results of motor actions on long-term memory used tasks that required or promoted attention to motor actions. When participants learned about novel tools, action information was explicitly presented during study and action manipulations during memory retrieval had some effect (Matheson et al., 2019; Paulus et al., 2009). Using familiar objects, Dutriaux and Gyselinck (2016) showed that memory for object pictures was affected by whether the participant's posture during the study phase allowed actions with the objects or not. The instruction to adopt a speci□ic pose (i.e., to hold one's hands behind the back) may have been unusual enough to attract attention to hand actions. Canits et al. (2018), however, found no effect of grasp congruency during study, but in that study, the grasping action was integrated in a categorization task, and therefore may have been less obvious to participants. Overall, this handful of studies suggests that effects of motor actions on memory for objects depend on explicit attention to motor actions when memory representations are created. Recent accounts of grounded cognition have included □lexible representations that are grounded in sensory-motor processes but do not have a conceptual core (Barsalou, 2016; Lebois et al., 2015; see also Meteyard et al., 2012). Rather, representations only consist of features that are needed in the current context. In this view, it makes sense that object representations only included motor knowledge if such knowledge was in the focus of attention during the study phase. In our present experiment, there was no focus on actions during the study phase, and we obtained no evidence that motor knowledge was part of the memory representations.

Alternative Explanations

Regarding the mixed results in short-term memory, two alternative explanations have been provided for the difference in results across short-term memory studies. First, Downing-Doucet and Guérard (2014) proposed that the motor system might play an important role

in keeping order information, which would explain why manipulations of motor action are obtained in studies in which the memory task was serial recall rather than free recall or item recognition. If the motor system is used mainly to retain the order of items, its role might be very limited in long-term memory. Second, Guérard and Lagacé (2014) have suggested that motor information is only beneficial when it can be used to distinguish items from each other. According to them, the lack of effect in some of the short-term memory studies is due to the similarity in actions that would be performed to grasp the studied objects. In our current experiments, however, the lists were composed of a mixture of manipulable and nonmanipulable objects, and the manipulable objects differed from each other in the actions that they afforded. Moreover, whereas similarity can hurt short-term memory performance, in long-term memory, similarity might actually result in a benefit due to organizing processes that may operate on unorganized lists, as has been found for categorical similarity (Lewis, 1971). Thus, neither explanation seems to fully account for the mixed results. We propose that, as in long-term memory studies, the differences between results in short-term memory studies is also most likely due to the differences in how much attention to motor actions the studies induced, where studies that focused on motor actions were more likely to find positive evidence for a contribution of the motor system than studies that did not focus on motor actions.

Conceptual Knowledge

In general, conceptual knowledge plays a larger role in long-term than in short-term memory. Therefore, we expected that motor information would be more important in long-term memory (Zeelenberg & Pecher, 2016). In contrast, however, the current study did not provide evidence for this mechanism. The interference task occupied the motor system, which should have harmed recall if such spontaneously activated motor information had been encoded in the memory trace. That we did not find the expected interaction between motor interference and object manipulability suggests that motor information is not spontaneously activated during study and does not support memory for objects.

Interference manipulations, such as the ones used here, may be better suited to study the role of the motor system for cognitive processing than congruency manipulations. Studies that find relations between conceptual processing and motor actions often consist of a type of priming which does not necessarily show that motor actions are a fundamental part of the concept (Mahon, 2015; Masson, 2015). An important source of evidence for the automatic activation of motor actions is spatial alignment studies in which objects are shown with a graspable part (e.g., the handle of a frying pan) on the left or right. Participants respond faster if the graspable part is on the same side as the response hand than on the opposite side (Tucker & Ellis, 1998). This finding was interpreted as showing facilitation of a manual action as a result of automatically activated grasping actions, consistent with the idea that motor actions are fundamental parts of concepts. Other results, however, have indicated that the spatial alignment effect is more likely due to spatial correspondence between stimulus and response. For example, spatial alignment effects are also found when participants respond with their feet (Phillips & Ward, 2002), which cannot be explained by automatic activation of actions, and alignment effects disappear when there is no spatial response competition (Roest et al., 2016), suggesting there was no automatic activation of actions (see Proctor & Miles, 2014, for a review of spatial alignment effects).

Even if some evidence might point at activation of motor actions, it is questionable whether these are fundamental to the concept. Papeo et al. (2009) found only late effects of action words in the motor cortex and concluded that motor activity may result from understanding action words, but does not contribute to understanding. Moreover, Handy et al. (2006) found that motor activity is larger for unfamiliar than familiar objects, which suggests that motor activity is the result of effortful processing rather than automatic activation as part of a concept. Bub and Masson (2010) have argued that motor congruency effects depend on action intentions. Studies that have used interference to study the role of motor actions for object identification have produced mixed results (Matheson et al., 2014; Pelgrims et al., 2011; Witt et al., 2010), also suggesting that motor actions are not necessary for concepts and may even be used only strategically (Osiurak & Badets, 2016).

This conclusion, that motor actions are not automatically activated as part of concepts, appears to be at odds also with some accounts of grounding abstract concepts (Pecher, 2018; Pecher & Zeelenberg, 2018). For example, cognitive metaphor theory (Gibbs, 1994, 2005; Lakoff & Johnson, 1980, 1999) has often been proposed as a solution to the grounding problem for abstract concepts. The idea is that abstract concepts, for example ***power***, are metaphorically linked to a concrete concept, for example ***vertical position***, and thus are grounded in sensory-motor features of the concrete concept (Meier & Robinson, 2004; Zanolie et al., 2012). If the sensory-motor nature of concepts is flexible and context-dependent even for concrete objects, however, it seems unlikely that sensory-motor features are necessary for abstract concepts. Conventional metaphors may not even activate the concrete concept anymore (Bowdle & Gentner, 2005; see also Dove, 2016). Unless a novel metaphor is used to explicitly draw attention to sensory-motor features, there is no need to activate sensory-motor features to understand abstract concepts.

Conclusion

The idea that specific motor processes are necessary or fundamental to mental representations may be unsustainable. Rather, the cognitive system seems to flexibly use the motor system together with other representational mechanisms, such as systems for perception, emotion, introspection, and abstraction (Barsalou, 2008, 2016; Lebois et al., 2015; Mendelson Wilson-Mendenhall et al., 2011). Studies on long-term memory for objects, including the present experiment, show that memory representations do not necessarily include motor actions. Instead, memory representations may depend on features from other modalities, such as vision, abstracted semantic knowledge, such as categorical knowledge, and linguistic or other amodal symbols (Dove, 2009; Zwaan, 2014). The idea that memory is for action might hold only in situations in which there is indeed an intention to act.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_14

14. Embodied Perception and Action in Real and Virtual Environments

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Abstract
In this chapter, we argue that the body is an essential factor in how people scale their perceptions of and actions in both real and virtual environments. We first review work showing that the size and posture of the body can influence perception and decisions about action in the real world. For example, the perception of whether real-world apertures can be walked through is scaled to the current position of the body (i.e., holding the body in a wider stance leads to the need for larger apertures in order to pass). We then show that conveying a different visual body size to observers using virtual reality can produce changes in the perception of scale in virtual environments. For example, observers may rescale their perceptions of what they can step over when embodying a different sized foot in virtual reality. Finally, states of the body, such as emotions, may also play a role in perceptions of certain aspects of the scale of real and virtual environments. Overall, we argue that embodiment contributes to perceptual and action processes, allowing us to scale the world according to our body's current action capabilities.

Keywords Perception and action – Virtual reality – Embodiment – Emotion – Affordances

One of the most important tasks that the visual system performs is to construct an accurate representation of the spatial layout of the environment. Accurate representations are necessary for successful action (like navigation) as well as for planning future actions. Traditional descriptions of how these spatial representations are formed have focused on how we construct the three-dimensionality of the environment, such as the distance to objects and their sizes. Our visual system has evolved to construct representations by capitalizing on visual cues in the environment as well as physiological cues inherent to the eye. To be sure, these cues are often sufficient to accurately represent the geometry of the environment. However, recent research suggests that information specified by the body, whether physical information for body size or emotional information about the state of the body, can also contribute to perceptions of the spatial layout of the environment (Proffitt, 2006; Proffitt & Linkenauger, 2013; Stefanucci et al., 2011).

In essence, this argument—variously termed the embodied perception approach (Barsalou, 2008; Glenberg et al., 2013; Proffitt, 2006) or cognitive penetrability (Stokes, 2013)—is that top-down processes, including assumptions and prior knowledge about the environment intrinsic to the observer, can be used to form a more coherent and accurate perceptual representation. Prior work suggests a role for top-down processes (aside from the state of the body) in perception. When objects are moving but the motion appears ambiguous, memories of those objects may influence interpretations of the direction of motion (McBeath et al., 1992). Further, recognition of an object can aid in perceiving its depth (Peterson, 1994). Recent research suggests that action and intent to act can influence how observers perceive the space in which they are acting (Witt, 2011, 2017). For example, Witt et al. (2005) found that the use of a tool to increase participants' reachability influenced their perception of how far objects just out of reach were from them. Finally, top-down processes such as emotion and motivation have been shown to influence the perception of faces (Halberstadt et al., 2009), as well as contrast sensitivity, which is thought to operate through an interaction between the amygdala, visual cortex, and other regions that direct

attention (Phelps et al., 2006). Our own work suggests that emotion also plays a role in perceiving heights (Stefanucci & Proffitt, 2009).

To be fair, embodied approaches are not the first to postulate a role for the body in perception. Gibson's ecological approach (Gibson, 1979) claimed that perception cannot be achieved without taking into account the body of the observer. In other words, perception is a synergistic activity; perceiving what the environment affords in terms of action is only possible if observers perceive the environment in terms of the capabilities of their bodies (see also, Warren, 1984). For example, a ball is perceived as graspable only if it is small enough to fit within the observer's hand. Likewise, an aperture is only passable if it is wider than one's body (Warren & Whang, 1987). Thus, the body is an integral piece in the solution to the perceptual problem. A more detailed discussion of work supporting the ecological approach will ensue in the following sections.

We begin this chapter by reviewing the literature that provides evidence for the role of the body (its physical characteristics and its emotional states) in perceiving and acting in space. We then discuss how (1) visually manipulating the size of the body in virtual reality (through the use of visual avatars or graphical representations of the body) and (2) manipulating the emotional state in virtual reality may allow us to better understand and test the body's role in perception and action. Virtual environments (VEs) are a unique tool for addressing theoretical questions such as whether physical body size and emotional body state influence spatial perceptions and judgments about action because they allow for manipulations of visual body size and emotional state that are often impossible or cumbersome in real environments (e.g., changing the visual size of the body or taking participants to a tall height). We conclude with a discussion of how body-based perception may be useful for real-world applications, and how critiques of body-based approaches to perception and action may help refine testing of theoretical questions in the future.

Measures of Perception and Action

The goal of the visual system is to recover from the 2D proximal stimuli (the light present on the retina) the three dimensions of the

distal stimuli (or the geometric properties of the natural world). Several visual cues in both the environment and the physiology of the observer allow for accurate perceptions of space and other stimuli without taking into account body-based information. For example, the thickness of the lens of the eye (as controlled by the ciliary muscle) can provide information about the depth of an object viewed within arm's reach. Pictorial depth cues such as linear perspective can provide information about the distance to objects. And shading can provide information about the curvature of a surface in the environment. However, neither physiological nor pictorial depth cues can account for all perceptions of geometric space. Here, we review terminology and aspects of studying the perception of spatial layout relevant for understanding how body-based information may play a role, as covered in the sections that follow.

The extent to which visual and physiological cues provide information regarding the layout of space is often defined by the measure used to assess perception. Spatial information can be assessed in either an absolute or relative manner. We assess absolute spatial information by asking observers to report what they see in some type of fixed unit or standard. These units or standards may be culturally defined (e.g., feet or meters), or they may be defined relative to the observer's body (e.g., eye height or arm length). In contrast to absolute assessment, we can assess relative information about spatial layout by asking observers to compare geometric properties within the environment. It is important to note that this relative comparison does not necessitate being able to report on absolute information about either property. An example of a measure that assesses relative depth information is visual matching, through which observers are asked to adjust one depth interval to be equivalent to another. Such tasks can also be used to assess other properties of space, such as object size (Kenyon et al., 2007).

We also need to consider the frame of reference in which spatial information is observed. In the case of judging distances, space can be viewed either with the observer's point of view as a reference point from which distances are judged (termed an egocentric frame of reference) or with two external objects (neither being the observer) as reference points for judging an extent (termed an exocentric frame of

reference). Prior research has focused mostly on egocentric absolute distance perception. In addition, distances judged can be categorized according to where they are in space relative to the observer, as proposed by Cutting and Vishton (1995). Specifically, they defined three regions of space: personal, action, and vista. Personal space is the area immediately around us (roughly the space within arm's reach). Action space is the area from personal space up to about 30 m; here we can easily and immediately interact with objects. Vista space encompasses all distances beyond action space. The accuracy with which traditional visual cues can be used to judge spatial layout in each of the areas of space varies, with the number of cues specifying distance decreasing as space from the observer increases. For example, eye height can be used as a cue for distance perception in action space but not personal or vista space. Binocular stereo is a cue for absolute distance in personal space but not action or vista space. Very few (if any) useful cues provide information about far vista space (or vast spaces, see Klatzky et al., 2017).

One of the most challenging aspects of studying space perception is accurately assessing what people truly "see." As soon as people are asked to report what they see in some way, cognition can intervene and potentially bias responses (Loomis & Knapp, 2003). Although space itself can be measured neatly in increments (such as feet or meters), observers asked to report distance in those absolute units must rely on a stored metric to translate what they see into these units. For example, we can measure perception of space by asking people to verbally estimate how far away they perceive objects in the environment to be (in terms of some metric like centimeters or inches, which are absolute measures). However, an inaccurately stored representation of the unit can obviously result in biased reports. Further, different representations for units across observers can unnecessarily increase variability in responses. Cultural differences among observers, for example in which units they know and use, can also induce variability.

An alternative approach to measuring perception is to ask observers to perform an action rather than provide an estimate with an arbitrary unit. The assumption behind these types of action-based measures is that visual representations are needed in order to

precisely perform the action. In other words, the resulting action can provide insight into the accuracy of the underlying visual representation on which it was based. An example of such a measure is blind walking. Observers are asked to view a target and then to walk without vision to where they believed the target is located in space. Research suggests that observers are quite accurate at performing blind walking tasks up to around 20 m (Loomis et al., 1992; Rieser et al., 1990). Another example of an action-based measure is affordance judgments, in which observers report (from a static viewpoint) whether or not they can act in certain ways on the environment or objects within it (Warren, 1984). In general, work on judging affordances finds that observers can reliably judge whether they can perform actions given an environmental feature. Overall, the appeal of these action-based measures of perception is that they are often easier to understand, less prone to cognitive or response biases, and easily implemented (at least in the case of affordance judgments) in virtual environments where large-scale actions may be more difficult to execute given limited tracking space. We will discuss this advantage for action-based measures in VEs in later sections. The next section introduces how the body may play a role in spatial perception.

Embodiment in the Real World

Physical Body

The notion that the size of the body plays a role in the perception of the environment is not unique to recent embodied cognition approaches. Gibson (1979) posited nearly a half-century ago that the perception of what he termed ***affordances*** was only achieved through perceiving the body relative to the aspect of the environment being perceived. In other words, an object only affords grasping if one's hand is large enough to hold the object. Numerous bodily dimensions and their relationship to the perception of whether or not action is afforded by an environment have been investigated since Gibson's original claim. Bodily dimensions include eye height (Leyrer et al., 2011; Warren & Whang, 1987; Wraga, 1999), hand size (Linkenauger et al., 2011), leg and arm length (Creem-Regehr et al., 2014; Mark & Vogele, 1987), and other bodily properties. These body dimensions have been examined

for their role in judging affordances for sitting, stepping, passing through, reaching, grasping, and many more. Perception of affordances has also been investigated across the lifespan (Adolph et al., 1993; Hackney & Cinelli, 2013) and in other species (Wagman et al., 2017), with results suggesting accurate perceptions of action capability (albeit with some prior experience with the action needed).

Embodied perception approaches also posit that the body plays a role in perceiving the surrounding environment. However, the mechanisms by which the body plays a role are somewhat different than those proposed by Gibson's approach of affordances. For instance, Proffitt and Linkenauger (2013) claim that the body is useful information for perceiving the world around us because it provides a constant "ruler" with which to scale the world. Which units of the body are called upon and used for scaling depends on the intended action. If an observer is perceiving whether something is reachable, then the scaling unit becomes the length of the arm; however, if the observer is perceiving graspability, then the scaling unit is the size of one's hand. To be clear, embodied approaches do not claim that the body is always used to scale the world, but rather that it is a reliable unit that when manipulated has an effect on perceptions of spatial layout and action. Further, over evolutionary history, the body was a unit that was always present and could provide consistent information to scale spatial layout when other cues were lacking (Stefanucci et al., 2011). However, testing theories of embodied perception depends on the effectiveness of manipulating the body (either its physical size or its emotional state) to discern the effect of those manipulations and resulting bodily characteristics on perceptual scaling of spatial layout.

Altering physical body dimensions can be difficult to accomplish in real-world settings, but there is some evidence from unique manipulations to suggest that visual body size is used to scale the environment. For example, Linkenauger et al. (2010) manipulated the visual size of objects using goggles designed to magnify or minify object size. They asked participants to report the apparent size of familiar sized objects (e.g., baseball) and unfamiliar sized objects (e.g., wooden cylinder) and found that participants' reported object size was less affected by the minification or magnification goggles when they were allowed to place one of their hands on the table (the hand was not

magnified or minified by the goggles, but could be seen by participants), suggesting that they used hand size to scale objects in the environment. In contrast, Linkenauger et al. (2010) ran subsequent experiments in which a participant had a tool of familiar size or a researcher's hand present on the table instead of his or her own hand. These reference objects did not change perceptions, suggesting that one's own body may play a unique role in scaling the environment (but see, Collier & Lawson, 2017, for difficulty replicating some of these effects). Follow-up experiments by another research group showed that enlarging an observer's visual hand size while performing a reach-to-grasp task affected the maximum grip aperture of the hand, but not other kinematics of the reaching movement (Bernardi et al., 2013). However, making the visual hand size smaller did not re-scale the grip aperture.

We can also manipulate the body by adding objects to it that change action capabilities and/or alter its physical size or shape. For example, participants asked to judge whether they can pass through an aperture while holding a wide rod may underestimate the size of the aperture more than those not holding a rod (Stefanucci & Geuss, 2009). Raising observers' eye heights by asking them to stand on blocks resulted in greater accuracy in judging the height of a barrier they must walk under compared to another group asked to wear a helmet while making judgments (Stefanucci & Geuss, 2010). Interestingly, experience with the helmet (e.g., by wearing it often as an ROTC member) eliminated the bias in judgments of whether the barrier could be walked under without ducking. Wraga (1999) manipulated participants' eye heights (by employing a false floor not visible to participants) and asked them to judge the height of stairs and the width of apertures as well as whether they could step on the stairs and pass through the apertures. The effective eye height manipulation significantly affected participants' perception of environmental dimensions as well as their action capabilities (they underestimated their abilities when eye height was raised), even though they were unaware of it (as assessed through self-report at the end of the experiment). Altering participants' jumping capabilities by having them wear ankle weights affected perception of the width of jump-able gaps, but not gaps too wide to be jumped across (Lessard et al., 2009).

This finding is important in that it shows that manipulations to the body only affect actions that are possible for observers rather than any action. Witt et al. (2005) investigated the influence of holding a rod on the perceived distance to targets. The targets were placed outside of participants' reach without the rod but within reach of those holding the rod (rod holding was a between-groups manipulation). Participants judged targets to be closer when holding the rod compared to not, suggesting that physical body capabilities (even if augmented with a tool) can scale distance perception. This work was extended to biases in farther distance perception when observers' abilities to point to a target were augmented with a laser pointer (Davoli et al., 2012).

Taken together, the literature suggests that our physical bodies and their capabilities play a role in how we interpret and interact with the world. This conclusion has important implications for individuals who experience changes to their physical bodies, such as rapid growth in adolescence or the loss of action capabilities due to disease or injury. Natural changes in body dimensions also occur during pregnancy. Measuring real actions by asking pregnant women to attempt to walk through apertures showed that pregnant women did adapt to their changing body shape over time and accordingly adjusted their judgments of what they could pass through (Franchak & Adolph, 2014). With regard to clinical disorders, individuals with Anorexia Nervosa (AN) tend to overestimate the size of their body with a variety of measures (Gardner & Brown, 2014), and this misperception influences how they perceive their ability to act within an environment (Keizer et al., 2013). Body dysmorphic disorder (BDD) can also be accompanied by perceptual biases (Clerkin & Teachman, 2008), such that individuals high in BDD judge morphed versions of their faces that are rated less positive to be accurate representations of their actual face.

Similarly, pain influences body perception in patients who experience phantom limb pain, those with complex regional pain syndrome (CRPS), and those with other chronic pain (Lotze & Moseley, 2007). CRPS patients often misperceive the size of their affected limbs (Lewis et al., 2007), and about 80% of amputees experience phantom limb pain, which is the sensation of pain in a limb that is no longer part of their body leading to a profound body misperception related to pain

(Ephraim et al., 2005). Consequently, pain may serve as a bodily state that affects the perception of the environment and perceived ability to act within that environment. Chronic pain patients have been shown to judge distances as farther compared to healthy controls (Witt et al., 2009), and healthy participants with experimentally induced leg pain via a hypertonic saline injection subsequently underestimate affordances due to this pain manipulation (Deschamps et al., 2014). Still, with some mixed evidence on how chronic pain influences perception (Tabor et al., 2016), more research is needed to disentangle how pain might interact with perception (or vice versa). Additionally, the current research does not provide evidence about a potential mechanism by which pain may affect perception. Further, pain may indirectly affect perception by interrupting attention or another process that may affect how people respond to the perceptual tasks used in previous studies.

The Emotional and Motivated Body

Physical (and perceived) size are not the only bodily states that may affect perception and action in the real world. Work by our research group and others (see also the affect-as-information approach, Clore & Huntsinger, 2009; Storbeck & Clore, 2008; Zadra & Clore, 2011) suggests that emotional states of the body may serve as information with which to scale the environment, particularly when other visual cues for space perception are at a minimum (Stefanucci & Proffitt, 2009; Stefanucci et al., 2011; Teachman et al., 2008). Further, emotional effects on perception may be functional in that emotion can make important objects in the environment more salient, can motivate action, and may also conserve bioenergetic resources (Stefanucci et al., 2011; Zadra & Clore, 2011). Finally, emotion affecting perception (e.g., in the case of fear) may have had evolutionary consequences (Stefanucci et al., 2011). Consider perceiving heights (or vertical distances)—many of the most useful cues for understanding distance (linear perspective, horizon ratio) rely on the assumption that the observer is standing on the ground plane (Gibson, 1950), but in the case of heights the observer is off the ground. Thus, participants overestimate heights viewed from above looking down by nearly 60% (and by about 30% when viewed from below), and this overestimation

correlates with self-reports of trait- and state-level fear (Stefanucci & Proffitt, 2009). In a more direct test of the effects of emotion on perceiving heights, viewing arousing images (which subjectively increased arousal ratings of participants) before estimating a height from above increases overestimation of height (Stefanucci & Storbeck, 2009), but does not affect the perception of distances in a non-threatening hallway (i.e., an extent for which information about arousal is irrelevant). But, if self-reported arousal is increased by asking one group of participants to judge the distance to or across a threatening situation (such as a pit of nails and broken glass), then perception of the extent (as measured with a visual matching task) is overestimated compared to a group judging the same extents in a non-threatening situation (Stefanucci et al., 2012). In all of these cases, emotion motivates the observer to act in a certain (non-dangerous) way by altering perceptions of the environment to ensure safety.

This effect of emotion on perception generalizes to other environmental situations. For instance, arousal affects judgments of the size of a beam that observers anticipate walking across. Aroused participants deemed the beam to be narrower (as assessed with a visual matching task) than non-aroused participants (Geuss et al., 2010b). Participants made anxious by breathing through a narrow straw underestimated their ability to reach to, reach through, and grasp objects compared to a different group of participants who breathed through a wider straw (Graydon et al., 2012). People asked to think about a friend while standing at the base of a hill (assumed to evoke positive feelings) verbally estimated the hill to be less steep (and visually matched it to be less steep) than those asked to think about an enemy (Schnall et al., 2008). Participants who reported feeling sad after listening to melancholy music estimated hills to be steeper than participants who listened to happy music (Riener et al., 2011). Participants who experienced fear due to standing on a skateboard at the top of a hill and thinking about going down it estimated the hill to be steeper than those not afraid (Stefanucci et al., 2008). Participants higher in trait fear of heights overestimated heights more than those who are low in trait fear, even when controlling for cognitive biases associated with the high-trait fear (Teachman et al., 2008). Emotional content also affects size perception; circles filled with negative stimuli

were judged to be larger than circles containing positive stimuli (van Ulzen et al., 2008). Finally, even basic visual processes such as contrast sensitivity can be enhanced by fear (Phelps et al., 2006). Manipulation checks are always important in emotion research, and all of the work mentioned here acquired subjective reports of emotion (mostly at the end of the experiments) to validate that participants were feeling the intended emotion during the study if emotion was manipulated.

In addition to emotion, motivational states have also been shown to influence the perception of space. For example, thirst affects the perception of transparency; dehydrated observers often report seeing surfaces as more transparent, an important property of water (Changizi & Hall, 2001). Additionally, participants estimate desirable objects (such as a water bottle when they are thirsty) to be closer (Balcetis & Dunning, 2010) and the distance to desired locations as shorter than undesirable locations (Alter & Balcetis, 2011). Further, participants who are fluid deprived (as assessed through self-report) estimate a glass of water to be larger when primed to think about drinking, compared to a group that is not primed to think about drinking (Veltkamp et al., 2008). Motivation to approach or avoid an object in the environment may also influence perception. Threatening objects appear closer, while disgusting or neutral stimuli appear farther away (Cole et al., 2013). However, most of the work reporting an effect of motivation on perception controlled for arousal, which suggests that motivation and arousal may affect perception through different underlying mechanisms or systems (Balcetis & Dunning, 2007). For a more complete review of approach and avoidance as aspects of motivated perception, see Balcetis (2016).

Embodiment in Immersive Virtual Environments

The use of immersive virtual reality to support training, learning, simulations, and other applications increases daily with the advent of new, cost-effective, and commodity-level head-mounted displays (HMDs). Effective use of these technologies for these applications relies on an understanding of whether people experience and learn from virtual worlds in the same ways that they do in real

environments. Specifically, do people see and act in virtual environments as they do in the real world? These questions are especially important to answer in applications for which accurate spatial representations are needed (surgery, architecture, etc.). Another important recent change to these technologies is the easier implementation of self-avatars, that is, graphical representations of the observer in a virtual environment. Increasing the use and implementation of self-avatars allows for manipulations of visual body size not easily accomplished in real environments. We argue in the remainder of this chapter that virtual environments provide researchers with a unique tool for testing embodied theories, and we present recent evidence from our laboratory and others to support this claim.

We define ***virtual reality*** (VR) as the "use of computer graphics to perceptually surround an observer so that he or she has the experience [of] being in a simulated space" (Creem-Regehr et al., 2015b, p. 196). Available VR systems vary in tracking abilities (e.g., eye-tracking, hand and foot tracking, full-body tracking), tracking range (e.g., whether an observer can walk in a large space), and immersion, the extent to which the virtual environment completely removes the observer from the real environment. Some systems, such as the HTC Vive and Oculus Rift, use an HMD to completely immerse participants in a virtual world, while other systems use a collection of screens to surround users with a simulated environment (e.g., a CAVE, Cruz-Neira et al., 1993). Augmented reality (AR) is an additional technology that simply displays virtual objects in the context of the real environment (see Fig. 14.1). An example of AR is the Microsoft HoloLens, but readers may also be familiar with AR phone apps, such as Pokemon Go. With current technologies, one major difference between VR and AR is the field of view (FOV) in which virtual objects are rendered. Human vision provides a field of view that is approximately 180 degrees horizontal. Whereas in recent years VR has achieved a large FOV with technological advances (e.g., most of the new technologies have a FOV of up to 110°), AR technologies have struggled to provide wide viewing areas. The HoloLens, for example, can utilize only a roughly 40-degree FOV. Because of the differences in immersion and viewing capabilities across technologies, researchers in the field have broadly named the

whole category of technologies mixed reality or XR. For the rest of the chapter, we will focus primarily on immersive virtual reality technologies, but, when appropriate, we will mention if other types of mixed realities were used to test embodiment.

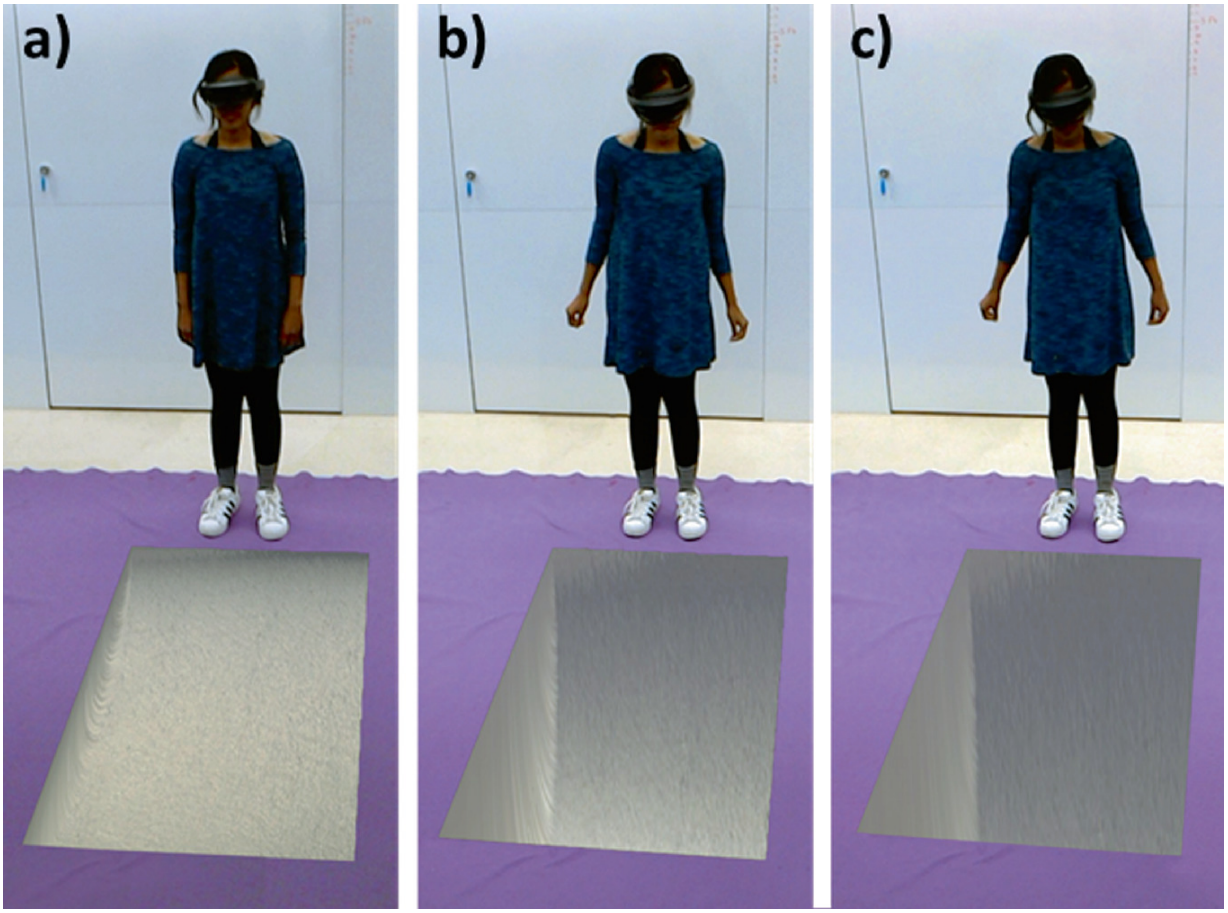


Fig. 14.1 Virtual pits of varying depth, a shallow, b medium, and c deep as displayed in augmented reality using the Microsoft HoloLens 1. Reprinted from Wu et al. (2019)

Perceptual Fidelity

VR is a particularly useful tool for perception researchers because it often exhibits greater ***ecological validity*** than other laboratory paradigms, and it allows for the use of many action-based measures (especially with large tracking areas). As stated earlier, if the body is represented in the virtual environment, then VR allows for manipulations of body size and motion that can be used to test embodied theories. An important matter to address before discussing how manipulations of bodily size and state can be achieved in VR is

whether or not observers perceive immersive virtual environments (IVEs) in the same manner as they do real environments. Our prior work describes this question as being one of ***perceptual fidelity***, which is the extent to which perception and behavior in an IVE is similar to that in the real world (see also Creem-Regehr et al., 2015a; Stefanucci et al., 2015, for more discussion of this topic). The perceptual fidelity of IVEs is extremely important to assess given that we often want to generalize findings from experiments using virtual environments to the real world. If observers perceive virtual environments in very different ways than real environments, generalization becomes much more difficult.

Perceptual fidelity can be measured by asking observers to perform absolute and relative perceptual tasks (such as verbal reports, affordance judgments, and visual matching) in the real world and then comparing real-world performance to that in immersive virtual environments. Past research has generally found compression of scale in IVEs compared to in the real world, with estimates in IVEs averaging between 40 and 80% of the actual value (Creem-Regehr et al., 2015a; Renner et al., 2013). For example, Sahm et al. (2005) compared real-world and IVE performance on a blind walking (walking without vision to a previously viewed target) and a blind throwing (throwing without vision to a previously viewed target) task and found that, in the IVE, participants walked and threw to distances 70% of what they did in the real world, suggesting they perceived the distances as shorter in the IVE compared to the real world. Mohler et al. (2006) compared real-world and IVE performance for both blind walking and verbal reports and obtained similar results. As Creem-Regehr et al. (2015a) as well as Renner et al. (2013) reviewed, until recently, studies using HMDs consistently found this underestimation in IVEs. With the advent of the newer commodity-level HMDs, this underestimation has been reduced, suggesting that wider fields of view and less tracking latency may have contributed to the originally observed underestimations, although these factors have not been tested directly (Buck et al., 2018; Creem-Regehr et al., 2015b).

In contrast to the findings for distance perception, affordance judgments are generally similar across IVEs and the real world. For example, Geuss et al. (2010a) asked participants in the real world or a

closely matched virtual environment to view an aperture displayed by a gap between two poles and then to (1) blind walk to the location of the poles, (2) provide a size-matched estimate of the size of the gap between the poles, or (3) predict whether they could pass between the poles. For the VR condition, the poles were virtual. The poles varied in distance from participants (3, 4.5, or 6 m) and in terms of the size of the gap between them (25–50 cm) across trials (see Fig. 14.2). Geuss et al. (2010a) used three different perceptual measures to determine whether affordance judgments were affected by the distance compression seen with both blind walking and verbal report tasks in IVEs previously. For blind walking, participants underestimated the distance to the poles, as observed in previous studies. However, affordance judgments and size-matched estimates were similar in the real and virtual worlds, indicating that affordance and size judgments may not be susceptible to the same perceptual biases found for distance perception.

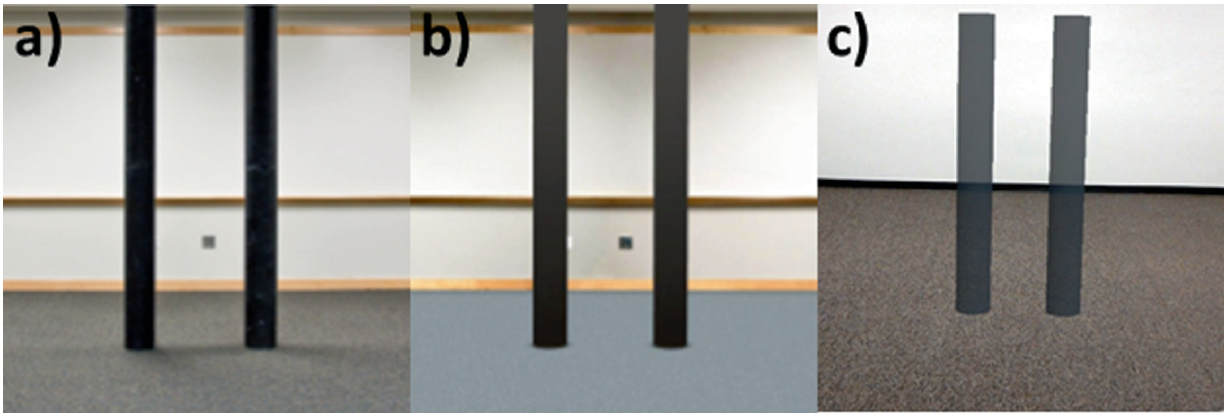


Fig. 14.2 View of the poles used in Geuss et al. (2010a) and Pointon et al. (2018) as displayed in a real world, b VR, and c AR

Pointon et al. (2018) tested whether Guess et al.'s (2010a) findings replicated in augmented reality. They presented participants with two vertical poles, the distance of which from the participant varied (3, 4.5, or 6 m), as did the width between the poles (30–60 cm). In the first block of trials, participants viewed the poles and provided a "yes/no" judgment of whether they could pass between them. In the second block, participants viewed the poles and then blind walked the distance to them. Pointon et al. (2018) compared performance in AR to the IVE

and real-world results from Guess et al. (2010b) to determine whether action-based measures could be used to determine perceptual fidelity in AR. Comparing performance across environments showed no significant differences between passability judgments in the real world, IVE, or AR. Notably, while Geuss et al. (2010a) found significant differences between the blind walking performance in the real world and in immersive virtual environments, Pointon et al. (2018) did not find a significant difference in blind walking performance between augmented environments and the real world. Taken together, these studies demonstrate the importance of testing the perceptual fidelity of virtual technology as well as the utility of action-based measures for conducting perceptual research in both virtual and augmented reality.

Within immersive virtual environments, the body is represented using a self-avatar, or a graphical representation of the user. Self-avatars can be human-like in appearance, or they can be stylized to be different than the human body. They can also represent just one body part, such as the feet or hands, instead of the entire body. Self-avatars may increase the perceptual fidelity of virtual environments. For instance, observers give more accurate egocentric judgments of distance within a virtual environment when a full-body, self-avatar is present (Mohler et al., 2008, but also see McManus et al., 2011); the improvement in accuracy of distance perception is even greater if the self-avatar is animated to follow the participant's real movements (Mohler et al., 2010). The perceived size of virtual objects is influenced by the presence and size of a virtual hand (Linkenauger et al., 2013). With regard to affordance judgments, the presence of a self-avatar improves estimates of stepping over or ducking under a pole (Lin et al., 2012) and stepping off a ledge (Lin et al., 2013, 2015). These findings provide support for the notion of the body as a "perceptual ruler" with which we perceive and scale the environment to inform action.

Manipulations of Physical Body Size in Virtual Environments

As previously stated, the body is an important source of information for perception. From research done in the real world, we know that manipulating the perceived size of one's body can have consequences for perception and, in turn, behavior. In IVEs, people will embody a

virtual avatar and localize themselves toward the presented location of that avatar (Lenggenhager et al., 2007). Prior work also suggests that observers readily accept self-avatars as their own even when the self-avatar body is grossly different in size from one's own body (Piryankova et al., 2014b). For example, adults can adopt a child-sized body as theirs in virtual reality (Banakou et al., 2013). Whereas modifying the perceived size of a body can be difficult in real environments, self-avatars are easily manipulated in virtual environments. Subtle manipulations of body width and shape have been used to gauge how effectively women recognize their own body size, with results suggesting that women accept a margin of error of up to 6% change in body mass index (BMI) as still their own perceived size (Piryankova et al., 2014a). However, one's own body size can influence the sign of the error such that women with a higher BMI are more likely to allow for positive margins of error than women with a lower BMI (Thaler et al., 2018).

Further, when the size of a self-avatar is altered, people may perceive the environment differently and scale their abilities to act accordingly in that environment. For example, participants who embody a child-sized avatar will overestimate the size of objects in their environment with a visual matching task compared to participants who embody an adult avatar (Banakou et al., 2013). Similarly, participants who virtually embodied a giant judged objects and distances to be smaller and shorter than participants who virtually embodied a doll (Van Der Hoort et al., 2011). Participants when shown big virtual feet, and asked what they could step over in a yes/no affordance judgment task, estimated that they could step over larger gaps than those shown small virtual feet (Jun et al., 2015). Similarly, when participants are presented with larger virtual hands (Linkenauger et al., 2013) or longer virtual arms (Day et al., 2019), they estimate that they can grasp larger objects and reach objects that are farther away, respectively. However, the effect of increased arm length on reaching estimates depends on having some experience with moving the arm (Linkenauger et al., 2015).

As previously mentioned, adult participants will adopt a child-sized virtual body (Banakou et al., 2013), and then may use it to scale the environment, resulting in an overestimation of the size of objects

(Tajadura-Jiménez et al., 2017). This finding was replicated in an older adult population, as well, but the embodiment effect only occurred when auditory signals were congruent with the presented body (i.e., a child's voice accompanying a child-sized avatar vs. one's own adult voice accompanying the child-sized avatar; Tajadura-Jiménez et al., 2017). In addition to scaling their bodies to the dimensions of an avatar, people may also adopt the actions of an avatar as their own. When visual information about movement is mismatched with actual movement, participants are poor at discriminating their own movement from that of an avatar, suggesting that they adopt the movement of the avatar as their own (Debarba et al., 2018). Further, when participants are given feedback about virtual reaching, regardless of the anthropomorphic fidelity of the avatar presented, judgments of what is reachable in the virtual environment become more accurate (Ebrahimi et al., 2018).

Evoking Emotion with Virtual Reality

As previously stated, emotion is an important aspect of embodied perception approaches, and a great perk of using VR as a research tool is that we can easily create environments and paradigms that evoke emotion, which allows us to test emotion's effect on perception and affordances. One of the first studies to demonstrate this capability showed that a virtual pit could elicit a strong sense of presence (the belief that one is truly in the virtual environment as if it were real) in an immersive virtual environment as assessed with a questionnaire (Usoh et al., 1999). Follow-up studies that directly assessed emotion through the use of physiological measures (e.g., heart rate variability) also showed that IVEs can reliably alter emotion by increasing the perception of risk (Meehan et al., 2002, 2005). More recent work has shown that IVEs can be used to evoke a range of emotions including joy, sadness, boredom, anger, and anxiety (Felnhofer et al., 2015). This work exposed participants to virtual parks that differed in the mood that they intended to induce (i.e., for anxiety, the park was presented with less illumination so objects were harder to see) and showed that each of the parks reliably induced the intended emotion through self-reports from participants. More recently, brain activations and heart rate have been shown to vary in virtual environments intending to

evoke emotions that differed in the level of arousal and valence (Marin-Morales et al., 2018). Further, variance in the brain and heart signals was able to be classified in a model in order to predict the emotional experience of the participants.

Given that IVEs are useful tools for inducing emotion, they allow for testing effects of embodied states on the perception of space. For example, Geuss et al. (2016) created a virtual environment in which participants were asked whether they could step over gaps of different widths and visually match the extent of the gap. Participants made these estimates on a platform raised 15 m in the air and on the ground (see Fig. 14.3). Conducting a similar experiment in the real world would be challenging for many reasons (i.e., difficulty in varying the height and increased danger for participants), which further demonstrates the usefulness of IVEs for inducing emotion. Geuss et al. (2016) found that observers reported higher ratings of subjective distress when the platform was farther off the ground, and this manipulation of fear was associated with participants overestimating the size of the gaps and underestimating their ability to step over them. Moreover, the magnitude of the respective over- and underestimations increased as height increased.



Fig. 14.3 View of a gap from the 15 m height. Participants stood at the edge of the brick surface and judged whether they could step to the other brick area. Reprinted from Geuss et al. (2016)

Recent work by our group using AR has also shown an effect of virtual depth on judgments of whether a gap can be crossed (see Fig. 14.1), with deeper gaps leading to more conservative estimates for gap crossing (Wu et al., 2019). Other fearful manipulations that could affect affordance judgments are more easily implemented with VR. For example, Regia-Corte et al. (2010) found participants were more conservative about whether they could stand on a slanted surface in an IVE when it was depicted as icy compared to wooden. With regard to personal space, virtual environments can be used to evoke fear by asking participants to place self-avatar hands with different visual appearances near dangerous things such as a spinning saw or to move the hands across dangerous things (like barbed wire) as measured with self-reports of ownership of the virtual hands (Argelaguet et al., 2016).

Immersive virtual environments have been used to study risky behaviors in children as well as adults. In her early work, Plumert (1995) related children's overestimation of their action capabilities to their accident proneness. Further work showed evidence for a relationship between misperception of abilities in children and risky behavior. Using IVEs, Plumert extended her work to more real-world tasks, such as bicycling across a busy street. For example, Plumert et al. (2004) used an immersive bicycling simulator to compare the street-crossing behavior of 10-year-olds, 12-year-olds, and college-aged adults. Although all participants selected the same gaps in traffic during which to cross the street, the 10- and 12-year-old participants took longer to begin crossing and to reach the other side. Potential explanations for the age-related differences include a mismatch between the child participants' perceived abilities to safely cross the road within the gap in traffic and their perceptions of how quickly the cars would approach the crossing line. In follow-up studies that examined crossing behaviors after experience (especially with high-density traffic), 10-year-old children saw the most improvement in crossing decisions, but all age groups showed better decisions in terms of safely timing crossing behaviors (Plumert et al., 2011).

O'Neal et al. (2018) also examined crossing on foot (rather than a bicycle) in this virtual task and found that improvement in crossing decisions (i.e., less risky behavior) developed with age as well. Recent work in our lab has investigated the perception of stepping over a gap in children, teenagers, and adults in IVEs (Creem-Regehr et al., 2019). Creem-Regehr et al. (2019) presented participants with gaps of various widths in an IVE, at both ground level and elevated 15 m above the ground. Participants provided "yes/no" responses to whether they could step across the gaps. Consistent with previous findings in adults, all age groups underestimated their gap-crossing abilities when elevated off the ground compared to when they made their judgments on the ground. In general, though, children underestimated their perceived gap-crossing abilities more than teenagers and adults at the height, suggesting that an increased sense of risk in the children altered their decisions more than teenagers or adults. For a more extensive review of development of the perception-action system in children and adolescents, see Plumert (2018).

Conclusions, Applications, and Future Directions

In this chapter, we have reviewed literature that argues that bodily states, whether physical or emotional, influence perceiving and acting. These effects occur in the real world and in virtual and mixed realities. Moreover, mixed reality technologies are unique and useful tools for manipulating the visual body and testing its effect on perception and action. These findings lay an important foundation going forward for experiments assessing perception, action, and embodiment in mixed realities. We would be remiss, however, if we did not discuss critiques that have surfaced regarding embodiment and perception and action. As we stated at the beginning of this chapter, one of the hardest aspects of conducting research on visual perception is simply that it is challenging for participants to accurately and reliably report what they see. As soon as participants form an overt response to describe their perceptual experience, an opportunity arises for cognition to potentially interfere with the perceptual experience. In other words, can we be sure that reports of perceptual experiences are purely based on perception and not on cognition? The short answer to this question, we believe, is no.

Some researchers have refuted claims that perception is being altered by embodied information in favor of an explanation that suggests that only reports are changed, not perception (Durgin et al., 2009, 2011; Woods et al., 2009). Recent reviews of the literature can speak more to this debate and to potential pitfalls that researchers conducting embodied cognition and perception work might consider in terms of experimental design and strength of claims (Firestone & Scholl, 2016; Philbeck & Witt, 2015). For the purposes of this chapter, we argue that determining whether embodied effects are purely perceptual or partly cognitive in nature is impossible and unnecessary. Clearly, the evidence presented suggests that, at times, we use body-based information to alter perceptual judgments. These judgments are the basis for decisions about future action, so whether the underlying change is purely perceptual or cognitively biased may not matter for behaviors that we care most about (estimates of and actions in space).

Further, the pioneering work on perceiving affordances and judgments of action capabilities has been less controversial; perceptual researchers generally agree on the use of body-based cues such as eye height, leg length, and hand size to scale the environment in terms of actions (see also Witt & Riley, 2014 for a review). Thus, while we take the criticisms seriously and readily concede that some of the observed effects may be biased responses rather than changes to underlying perceptual representations, we nevertheless believe that they are important and useful to consider for many spatial judgments and behaviors. In the following section, we suggest how understanding such effects may be even more useful for certain real-world applications.

Applications

Understanding how the body influences perception and action in both real and virtual environments has implications for applications in domains such as health, training, education, and design. In the real world, the body is always present and is generally within view. However, the inclusion of visual representations of the body in virtual reality is fairly recent. Therefore, the use of embodied or body-based information to aid in training or learning for particular applications is just beginning to develop. One of the most prolific areas thus far has been the health domain. For instance, bodily perception is especially relevant to the treatment of clinical conditions. When in pain, seeing one's body (e.g., one's hand) is analgesic (Longo et al., 2009), and this analgesia is modulated by portraying the hand as enlarged or reduced in size through the use of mirrors (Mancini et al., 2011). Although this work was conducted in the real world, doctors/health care providers are increasingly using virtual environments for effective pain management (Kenney & Milling, 2016; Malloy & Milling, 2010), and the analgesic effects of immersive virtual environments can be enhanced by including a virtual body (Martini et al., 2014). When an avatar is present in an IVE, especially when the participant self-identifies with the avatar, pain responses are reduced (Romano & Maravita, 2014). Further, physiological responses to painful stimuli seem to be modulated by the size and orientation of the presented body (Romano et al., 2016). IVEs are also being used to help improve body image

distortions in patients with Anorexia Nervosa (AN). Providing patients with a full-body illusion may change the way they perceive their environment, which provides therapeutic benefits (Keizer et al., 2016). For a comprehensive review of the use of virtual reality with body image and eating disorders, see Ferrer-Garcia and Gutierrez-Maldonado (2012). Outside of body-specific health domains, VR is effective in treating post-traumatic stress disorder (PTSD) and specific phobias (Maples-Keller et al., 2017).

In addition to its therapeutic uses, virtual reality can improve training in healthcare and other settings. Virtual reality is a training tool in various surgical arenas from orthopedics (Aim et al., 2016) to neurosurgery (Alaraj et al., 2011) to laparoscopic surgery (Alaker et al., 2016; Gurusamy et al., 2008; Yiannakopoulou et al., 2015). Medical simulations and training in VR have been applied in clinical training and assessment for medical (Matzke et al., 2017) and dental school students (Duta˜et al., 2011). In many medical settings, VR holds the promise of improving the quality of medical education and offers students and clinical practitioners the ability to practice skills that are difficult, expensive, or consequential to practice in the real world. VR training also has utility in scenarios outside of healthcare and has been used in education in the fields of architecture and construction (Wang et al., 2018). The applications of virtual reality for training and development are far-reaching and have been used in domains such as automotive development (Lawson et al., 2016), manufacturing (Choi et al., 2015), sports (Neumann et al., 2018), education (Freina & Ott, 2015), and military training (Lele, 2013; Pallavicini et al., 2015). For a more thorough review of applications than we can offer here, see Slater and Sanchez-Vives (2016). Accurate perception of space and action capabilities in virtual environments used for training in any of these domains is clearly crucial.

Future Directions

The last 10 years have seen a marked increase in the technologies available to researchers of perception and action for testing theories of embodiment. Virtual and augmented reality have provided unique capabilities for displaying the body and testing its effects on perception of and action in the surrounding environment. Future work

will be able to capitalize on even better body-scanning technologies that allow for easy and quick self-avatar creation (see Pujades et al., 2019 for an example of such capabilities). We foresee such technologies being used to test not only embodiment and its relation to perception and action but also more existential questions of how body size and shape may play a role in the sense of self. Certainly, the existing research suggests that body-based information contributes to perceptions of and actions in our environments. More work is needed wherein full-body information is manipulated with self-avatars (instead of simple arm or feet manipulations) to test reliance on the visual body to scale the environment. Manipulations of proprioception may also become possible with the development of better haptic devices for virtual reality (Garcia-Valle et al., 2017). More investigation of the use of body-based information for perception and action across the lifespan will also be important. We present some research on children and adolescents, but the new lighter-weight HMDs could also allow for testing older adults. Overall, we believe that virtual and other mixed reality technologies will be essential for pushing theories of embodiment in perception and action forward, and we encourage readers to contribute to such efforts.

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Part III
Social and Personality Perspectives

© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_15

15. Towards Theory Formalization in (Social) Embodiment: A Tutorial

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Abstract
Embodied—or grounded—cognition frameworks assume that human thought is affected by inputs from bodily modalities and the environment. But the embodied cognition literature, generally speaking, lacks the formal theorizing that allows for speciﬁc predictions about relations between body and mind. This problem is ampliﬁed by the fact that psychological research has encountered replication problems, challenges to validity of measures and manipulations, and overgeneralization of obtained ﬁndings to populations and measures that were not tested. This chapter provides a tutorial on how the ﬁeld can move towards formalized theories of embodied social cognition. We rely on research on social thermoregulation—the idea that social behaviors protect the body's core temperature—as a template for our tutorial. The chapter addresses the important questions of how to separate noise from signal in embodiment research, how to create reliable and valid

measures, and how to appropriately draw conclusions about the generalizability of obtained findings. We hope that following these recommendations will help theories in embodiment to become more formal, allowing for precise predictions about interactions between the body and human (social) cognition.

Keywords Embodied cognition – Social embodiment – Thermoregulation – Theory formalization – Meta-science

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Towards Theory Formalization in (Social) Embodiment: A Tutorial

The embodied, situated, or grounded cognition literature emerged as a response to the ***Symbol Grounding Problem*** (Harnad, 1990). Oversimplified, the position taken by scholars in this movement is that the body and environment are involved in cognitive processes to a greater extent than previously presumed (see Barsalou, 1999, 2008; Gibson, 1966; Harnad, 1990; Turing, 1950). The embodiment literature has been generative, giving rise to various theoretical positions ranging from ***Conceptual Embodiment*** (which focuses on introspection and mental representations, like ***Perceptual Symbols***: Barsalou, 1999, 2008) through ***Radical Embodiment*** (which usually denies the presence of any representational system and focuses more on external sensations: Alsmith & Vignemont, 2012; Gibson, 1966; Turvey, 2019) to ***Conceptual Metaphors*** (in which abstract information is thought to be represented by concrete experience via the blending of source and target concepts: Lakoff & Johnson, 1980, 1999). Examples of embodiment effects include the finding that thinking of trustworthy brands heightens the perception of ambient temperature (IJzerman et al., 2015b), that moving in space influences time perception (Boroditsky & Ramscar, 2002), that washing one's hands reduces cognitive dissonance (Lee & Schwarz, 2010), that gestures can influence the ability to process words (Glenberg et al., 2008), that physically standing outside a box leads to greater creativity (Leung et al., 2012), and so forth. But what if none of these findings are true?

These previously mentioned theoretical positions inspired considerable research. However, the vague and imprecise nature of

these theoretical positions means that the phenomena they seek to explain are not specified enough. This problem, in turn, makes generating predictions that could put various theories to test hard, if not impossible. We cannot but conclude that our "theories"—both in embodiment research and in psychology more generally—have become unfalsifiable and can be termed theoretical principles, at best. Fried (2020b) described such verbally expressed general principles as "proto-theories". They can be a good start to formulating a proper theory, but we cannot stop there.

When theories are verbal and not formalized, such as is often the case in our field, they become imprecise, explanations about effects will vary wildly, and arguments between theories often come down to which theory seems more parsimonious. Given the non-formal and imprecise nature of theorizing in psychological research, it is nearly impossible to use model comparison approaches such as Popper's (1962) falsificationism, which is a gold standard when theories permit precise predictions. Worse yet, there is now significant evidence that various effects in psychology (including those within the embodiment area) provide insufficient evidence to support the claims we make. What this means is that most of the claims that you read in this book may well be incredible, or, at the very least, need to be carefully examined. We think it is time to take a step back, revise how we approach research, clean up our field, and ascertain that what we generate as embodiment researchers is credible, and, more importantly, useful (IJzerman et al., 2020b).

This chapter provides an overview of our own attempt to build a formal theory in (social) embodiment. Admittedly, we are still working towards this goal and we are at the stage of generating ***statistical*** proto-theories (i.e., potentially robust effects without a clear explanation; we introduced a "statistical proto-theory" here to emphasize the transition between a statistical account and a genuine theory). In working on such a statistical proto-theory, we have already made some considerable progress, even meta-analytically, to check what robust effects can be found in the literature and we have also begun to appraise, develop, and perfect measurement instruments. This effort has been focused on the last author's work on social thermoregulation. From this point forward, we will restrict judgment,

reflection, and re-examination to that (social thermoregulation) field as we are quite familiar with its challenges. This does not mean that what we discuss should remain restricted to social thermoregulation; on the contrary, our urgent advice is to apply the exercise to all the research fields discussed in this book. To clean up the social thermoregulation literature, we have asked and keep asking the following questions (for another article making similar points, see Vazire et al., 2020):

(1) How can we separate statistical noise from ***potential*** signal in our literature (of which we are certain to be rife with publication bias)? [Establishing the robustness of findings and establishing a statistical proto-theory].

(2) ***If*** there is ***any*** signal within our literature, to what extent do the measures and manipulations that are relied on provide sufficient validity? [Assessing the validity of measurement].

(3) If there is insufficient validity of measurement and manipulations, how do we fix such problems to support the availability of proper measurement tools? [Improving measurement validity].

(4) Once measures are sufficiently sensitive to measure what we want them to measure, how do we arrive at sufficiently precise predictions, and how do we subsequently validate these predictions? [Generating precise predictions to establish a formal, explanatory theory].

(5) How can we appropriately hedge the conclusions we draw from our work so that we do not inappropriately overgeneralize? [Reaching appropriate conclusions].

We need to ask ourselves these questions in order to identify how to approach explaining robust phenomena ***before*** we move on to distinguishing between the different theoretical positions in the embodiment literature. We will first describe the general concepts we have in mind before characterizing their problems. After this

discussion, we will explain how we have been, and are still, trying to clean up the literature.

Social Thermoregulation and Its Problems

Thermoregulation is imperative for survival, and its importance is surpassed only by breathing. Simply put, if animals do not regulate their core temperature, they die. Temperature regulation is a constant struggle, as humans and other endotherms almost constantly need to respond to the demands of fluctuating temperatures (Cannon, 1932; IJzerman & Hogerzeil, 2017). One of the most effective ways homeothermic endotherms (warm-blooded animals that regulate temperature internally) solve this adaptive problem is by regulating temperature with others through various forms of cooperative warming, like huddling. This phenomenon is called ***social thermoregulation*** and is defined as a series of biological and social processes to help self and others maintain warmth. For example, huddling across homeothermic endotherms helps maintain a higher core body temperature and increases the efficiency of the metabolic processes that regulate temperature (Gilbert et al., 2010). In modern times, specialized adaptations for temperature regulation may seem redundant, but the period in which humans could use technology to regulate their temperature is—evolutionarily speaking—short. We should therefore expect the psychology of modern humans to bear the imprint of non-technological solutions to evolutionary problems related to temperature regulation. Since social thermoregulation consists of a series of biological and ***social*** processes, we can suspect that it influences our social lives, social behaviors, and intimate relationships. The efforts directed to explaining the phenomenon of social thermoregulation should include questions of whether and how temperature processes impact human social relations.

Research seems to support the suspicion of a relation between social thermoregulation and social behaviors—there is, for example, considerable neural overlap between social and thermoregulatory behaviors (Satinoff, 1978, 1982). Moreover, when temperatures drop, people have a greater desire to affiliate with others (Van Acker et al., 2016), and they think more of their loved ones (IJzerman et al., 2018a).

Correlations between network size, climate, and core body temperature suggest that people's integration in their social networks protects their core body temperature (IJzerman et al., 2018b). Thus, diminished social contacts likely threaten the regulation of core body temperature (for an overview, see IJzerman et al., 2015; IJzerman & Hogerzeil, 2017). Recently, studies with higher power have emerged (e.g., Fetterman et al., 2018), and a meta-analysis based on 26,037 participants and our own pre-registered replications confirmed that our evidence seems not to be built on statistical noise (IJzerman et al., 2018a). We have also confirmed that some new measures we have developed to study social thermoregulation are internally consistent—and to some extent—equivalent across various languages and cultures (Vergara et al., 2019).

But the news is not all positive as the literature still needs a lot of attention for it to be of use for theory and application. Many studies—including our own—have been underpowered (e.g., IJzerman & Semin, 2009, 2010; Williams & Bargh, 2008; Zhong & Leonardelli, 2008). Additionally, some follow-up studies have not successfully replicated original studies (Williams & Bargh, 2008, failed replication Lynott et al., 2014; original study Bargh & Shalev, 2012, failed replication Wortman et al., 2014) whereas others have (original study IJzerman & Semin, 2009; replication study Schilder et al., 2014) and others are disputed (Ebersole et al., 2016; IJzerman et al., 2016).

Potential culprits for these challenges to the robustness of the literature are publication bias (the tendency, common in peer-reviewed journals, to publish novel or 'exciting' results rather than nonsignificant conclusions) in combination with the previously named problem of low power and ***p***-hacking (intentional or accidental data manipulation to obtain a desired p-value). In addition, only very few successful studies in our literature have been pre-registered (for an exception, see IJzerman et al., 2018a) and insufficient attention has been devoted in our research to test whether manipulations and measures demonstrate sufficient construct validity (see Chester & Lasko, 2019; Flake & Fried, 2019 for discussions of the field as a whole). Further, most of the studies in this literature—including our own—have been carried out in Europe and the United States (and to a lesser extent in Asia and Oceania, but none in Africa and South

America). Finally, and important for the discussions in this book, various theoretical positions from the embodiment literature have been nearly impossible to test directly, causing researchers to usually infer one or another theory is superior based on parsimony (e.g., whether Conceptual Metaphor Theory and Radical Embodiment theories apply to these findings or not; see, e.g., IJzerman et al., 2018b; Beckes et al., 2015, for discussions). To push the field forward it is necessary to formulate precise (and risky) testable predictions.

General Roadmap

Working towards testable predictions requires us to take a step back and create a roadmap for how to recognize robust effects even before we can generate reliable, falsifiable theories. In part, this means determining whether an existing literature contains any reliable signal in it ***at all.*** Let us presume satisfactory signal is present in the social thermoregulation literature and that we are confident that the general principles (temperature has a link to social behavior) hold, such that we have a decent, scientifically informed understanding of the phenomenon. To ensure precision of prediction, though, we need to ensure that whatever has been measured in the literature has a meaningful equivalent to the concepts involved. In cases in which measures have been insufficiently validated, we are carrying out new validation work, which we then utilize in exploratory work to establish robust phenomena, which we can then turn into formal theories.

There are now various excellent discussions on formalizing theories (see, e.g., Devezer et al., 2020; Fried, 2020a, b; Robinaugh et al., 2020; Smaldino, 2020b; Van Rooij & Baggio, 2020; Van Rooij & Blokpoel, 2020), and there are many points of agreement between these authors. They all point out that psychology lacks and needs strong formal theories that will be able to explain robust phenomena (Fried, 2020b). Most of these authors also agree that too often theories and (especially statistical) models are often conflated or used interchangeably. We agree with Fried's (2020b) view that models are more particular than theories and that usually models are built to understand or describe a specific part of a theory. That models are very useful for recreating and understanding mechanisms of processes that

create phenomena: “models serve as intermediaries between theories and real world” (p. 2, Fried, 2020b).

Disagreement between the above mentioned authors seems to lie in the weight they ascribe to testing theories. While many authors stress how important, it is for a theory to generate testable predictions, Van Rooij and Baggio (2020) distance themselves from this view by emphasizing that “theories are neither ***for*** testing, nor ***for*** prediction” and that “testing is (...) a secondary research activity” (p. 4, Van Rooij & Baggio, 2020). The primary role of the theory is to explain psychological capabilities by proposing processes that produce the capacities. The comments of Van Rooij and Baggio (2020) propose that we should always add a theoretical research cycle to our usual research cycle and focus on building a theory before putting anything to test. Such theoretical work should help researchers in identifying what should be tested. In concert with these ideas, we see both theoretical and empirical cycles as important parts of the scientific process. For example, we agree with Devezer et al. (2020) that reproducible results are not necessarily true results and that false results may be reproducible. But we also think that the imprecision of current claims and theories—including in the social thermoregulation literature—prevents theories from being testable and, therefore, falsifiable.

To understand complex biopsychosocial phenomena such as social thermoregulation, we need to turn weak theories into strong theories by formalizing them into computational or mathematical models (Smaldino, 2020a). A weak theory—which principles of social thermoregulation can be characterized as—is an imprecise description of a phenomenon that does not allow for clear predictions. Weak theories can hide unknowns and assumptions, which is why it is almost impossible to test them statistically. Such hidden assumptions can be used to interpret any result in a desired way, which is particularly threatening to the field if it is coupled with low power, p-hacking, and publication bias. Weak—usually verbal—theories usually do not describe how variables relate to each other and they do not specify conditions for our effect to occur, nor do they specify—a priori—the expected effect size. Weak theories are also imprecise because human language is imprecise in its nature. (It is worth noting not all verbal theories are weak, but ours is. For example, Darwin’s theory of natural

selection is verbal, but also includes detailed explanation of the meaning of all relevant concepts).

In contrast, strong, falsifiable theories are precise, explicit, and much less prone to interpretation one way or the other. Strong theories also allow for inferences and, more importantly, a priori predictions. Weak and strong theories are two ends of a continuum that describes the precision of the theory (not at all precise—very precise). To arrive at a strong, falsifiable theory we need to "describe the behavior of a complex system in such a way that is meaningful for explanation and prediction" (p. 1, Smaldino, 2020a). We will describe how we have started working on all these steps in the following sections.

Establishing the Robustness of Findings and Establishing a Statistical Proto-Theory

First and foremost, we need to ask whether the phenomenon that we study is even sufficiently reliable to engage in a translation of a weak (verbal) theory into a strong (formal) theory? Given that most of psychology contains a large range of research findings that have almost certainly fallen victim to publication bias, we have two choices: discard all findings and start anew or try to conduct a meta-analytic assessment to assess whether these literatures have any signal in them at all. For the social thermoregulation literature, we decided on the latter.

What is it we have done to make our work more precise? To start with, it is well-known that the psychology literature contains a considerable amount of error (Nuijten et al., 2016). Before moving on with the meta-analytic assessment, we thus (1) need to check the literature, (2) exclude studies that are at very high risk of bias due to mathematically inconsistent means or SDs through an automated script (Sparacio et al., 2020; see also Anaya, 2016; Brown & Heathers, 2017), and (3) exclude studies that had extremely low chances of being a real effect (e.g., 1 study's effect size was so large that there was only a 1 in 1,000,000 chance that the effect size could be real; Huang et al., 2014, Study 4).

We then presumed that publication bias was present as a property of the publication process (Fanelli, 2012) and employed several

methods to help correct for publication bias as well as possible (with the understanding that there is no perfect way to adjust for bias). Using this analytical workflow, one can decide to continue or stop after conducting one analysis or the other. For example, when applying this workflow to another subfield of embodied cognition, the "cleansing effect", we found that some methods to detect publication bias already rejected evidential value, leading us to conclude that we did not need to continue this workflow (Ropovik et al., 2020).

For social thermoregulation research, we used an analytical workflow that implemented several methods to detect and correct for publication bias. As a detailed description of the methods used is beyond the scope of this chapter, we refer interested readers to the literature on these methods cited below. First, we estimated whether we could reject evidential value in the observed set of results relying on a p-curve (Simonsohn et al., 2014), using a permutation procedure in which we randomly included all p-values from the studies we had selected (also see IJzerman et al., 2012). We then tried to estimate the bias-corrected effect size to provide a more generalizable picture of the effect using a 3-parameter selection model (McShane et al., 2016) and a mixed-effect robust implementation of PET-PEESE (a meta-regression method commonly used to address small-study effects that are suspected to indicate publication bias: Stanley & Doucouliagos, 2014), but relying on the 3-parameter selection model as the conditional estimator for PET-PEESE. Only if ***all*** analysis methods demonstrated sufficient evidential value, we considered that we could not reject the signal.

Overall, our analyses showed sufficient evidential value in the literature (although not all parts of the literature had comparable evidential value. We did not find, for example, a solid foundation for the relationship between temperature and emotion; for more detail, see IJzerman et al., 2020a). Although research practices in social thermoregulation showed evidence of improvement over time, it was clear that the literature as a whole was underpowered, that there was considerable heterogeneity in the literature, and that predicting with precision was hard, if not impossible. To ensure that hypotheses are truly confirmatory and to get as close as possible to the real effect size(s), we need to exclusively rely on Registered Reports for

confirmatory work. In the absence of Registered Reports, one can rely on our Confirmatory Research Templates to structure and pre-register one's work (https://osf.io/qpdth/). But these assessments are far from sufficient for the development of a mature theory; we may have simply developed a statistical proto-theory that is reproducible, but for which the premises are still false.

Assessing and Improving Measurement Validity

Our meta-analytic assessment thus helped us conclude that some robust effects exist in the literature, but that this assessment does not allow us to make very fine-grained theoretical predictions. Part of this imprecision is due to insufficient statistical power. But it may also be the case that the measurements on which we rely simply produce noise (and we thus generate false, but reproducible effects). In psychology more generally (and in our own research specifically), information regarding the quality of measures and manipulations in the psychological sciences is often absent or poor (Chester & Lasko, 2019; Flake & Fried, 2019). Surprisingly little attention has been devoted to comprehensively evaluating the quality and validity of measurement instruments (Borsboom, 2006) and even less attention has been given in evaluating how measurement instruments perform across a variety of contexts (Vandenberg & Lance, 2000), which is important if one seeks to generate a theory that generalizes across humans. We suspected that these problems are present in the social thermoregulation literature. So how can we determine which measurement instruments capture signal and noise respectively, and how can we determine whether they exhibit sufficient global validity? And how can we fix things?

Four common criteria are used to establish proof-of-concept within the domain of measurement. First, one needs to establish that the items of an instrument measure something that is coherent amongst them (i.e., ***internal consistency***). Second, it is important that the instrument is measurement-objective across contexts and time (i.e., ***test–retest reliability***). Third, there needs to be a relationship between an observed variable and the underlying latent construct (typically

obtained via confirmatory factor analysis), and the instrument should be comparable across different populations (i.e., ***measurement equivalence***). In the past years, a vigorous debate has reemerged whether measurement practices in social and personality psychology are of sufficient quality (e.g., Hussey & Hughes, 2020; Wetzel & Roberts, 2020).

In preparation for this chapter, we decided to assess the information available on structural validity of the social thermoregulation literature, relying on the articles found by IJzerman et al. (2020) for their meta-analysis. First, it was not uncommon for authors to use measures for which no information on construct validity was available at all. In 103 out of 226 cases, authors relied on existing scales, and in 123 out of 226 cases, authors created their own scales. In 4 out of 103 cases, authors only used a subset or subscale of a measure. In the cases in which existing measures were relied on, they were not validated in independent studies, while measurement equivalence was not examined for the groups that were studied. For a few existing scales languages other than English were used. There was no information on whether the scales were only translated or if any factor analysis or measurement equivalence was examined for the new version.

For 1 out of 226 cases, test–retest reliability was examined and in another nine cases, interrater reliability was reported. No exploratory or confirmatory factor analyses were performed. For the measures reported, it was not common to report internal consistency for all the measures that were used. Only Cronbach's Alpha was reported in 68 out of 179 cases where internal reliability should have been reported (McDonald's Omega, which is often considered superior in assessing reliability, was not reported in any of the inspected articles).

These issues are problematic. To start fixing them, we have taken a step back to examine how we measure our concepts of interest. One of the problems we first encountered was that an otherwise well-validated attachment measure ***Experiences in Close Relationships***—did not estimate sufficiently well what we were interested in (attachment based on resolving basic survival concerns related to temperature regulation). When we examined moderating effects relative to a temperature manipulation, we discovered that it did not perform as

predicted. Using an exploratory-confirmatory approach, we found a few items could moderate the effect, but reliability was poor (IJzerman et al., 2018a). To remedy this problem, we developed a measure—the ***Social Thermoregulation and Risk Avoidance Questionnaire*** (STRAQ-1)—in which we measured people's desire to socially thermoregulate with others and conducted an independent validation study in 12 countries across the world (Vergara et al., 2019).

In a follow-up project involving the Social Thermoregulation, Risk Avoidance, and Eating Questionnaire [STRAEQ-2], we have started extending the measure by differentiating different aspects as they relate to thermoregulation—sensitivity to the need, desire to regulate alone, desire to outsource to others, and the confidence that others will be available when one desires outsourcing (Dujols et al., 2020). While the STRAQ-1 measure was internally consistent, it did not seem to be sufficiently equivalent across the different countries we tested in. One of the potential reasons for the poor performance across countries may be because we—the researchers—generated the items. Instead, in our follow-up project involving the STRAEQ-2, collaborators from 32 different countries generated statements that they thought applied to their population of interest for the various properties of thermoregulation we defined—sensitivity to the need, desire to regulate alone, desire to outsource to others, and the confidence that others will be available when one desires outsourcing. We will now further test and validate this measure in over 40 countries (Dujols et al., 2020).

Beyond developing these self-report measures, we also need to ensure proper validation of psychophysiological measures. Specifically, we have started developing a smartphone app via which we can measure peripheral temperature in the field on a second-to-second basis (IJzerman & Dujols, 2020). This smartphone app communicates data from the ISP131001 sensor that participants wear on their finger. To know how reliable this measure is, we validated it against another, better-validated measure (the MLT probe sensor) in a lab study (Sarda et al., 2020). In this study, 25 participants held their hands in either warm or cold water or were in a (passive) control condition. We compared the ISP131001's performance against the MLT probe sensor. While our sensor was somewhat less reliable, it did have a high

correlation with the MLT probe if we averaged two sensors. The data in our training set showed that while the sensors correlated (sensor 1, r = 0.55; and sensor 2, r = 0.36) with the MLT probe sensor, a greater correlation was obtained by having both a sensor on the finger and on the wrist (mean of the two sensors, r = 0.82). In a follow-up confirmatory analysis that was only conducted after an in-principle acceptance of the article, we replicated these findings with r = 0.94. Accordingly, we have invested funds into a further development of our smartphone app that allows the communication of the phone with two sensors concurrently (the code of this mobile application (Bio-App) is open source and can be found at https://github.com/co-relab/bioapp). While this validation study shows sufficient reliability of the ISP13001 sensor in the lab, it still is mute regarding its performance in the field, an application that requires further work. Finally, we are also planning to engage in construct validation of some of our manipulations, as we plan to run such tests with a device we use in our lab to manipulate temperature, the EmbrWave.

Generating Precise Predictions to Establish a Formal, Explanatory Theory

A general problem with translating measures into theory in social sciences is that they belong to what is sometimes referred to as "inexact science" (Griesemer, 2013), which results in an imprecise overlap between theory and models. One of the problems that we have encountered while performing our systematic review is that we had insufficient information to examine moderations of an effect (IJzerman et al., 2020). This was usually due to individual studies being too underpowered to examine two- or three-way interactions, but also because, across studies, researchers hardly ever measure the same constructs. To try to confront this problem, we have recommended to researchers that they rely on a protocol to measure constructs that we have found (in a supervised machine learning study) to correlate with core body temperature (IJzerman et al., 2018b; Sarda et al., 2020; for the protocol, see https://osf.io/xf7uk/; while we have recommended measures that are reasonably well-validated, this protocol is due for further improvement once better measures have been developed).

This will allow us, as Tukey (1977) argued, to generate a plausible and coherent set of predictions from data. An important part of generating more precise predictions and more robust phenomena is to utilize exploratory research methods. Exploratory work allows the researcher to pose informed questions and identify parameters that are needed to generate precise hypotheses (instead of relying solely on "expert" knowledge). In our own research, we have frequently found ourselves to have made the wrong predictions (e.g., IJzerman et al., 2018a; Van Acker et al., 2016). Ideally, the exploratory phase helps researchers get rid of at least some of the misconceptions they had prior to data collection. Exploratory research thus does not solely rely on large datasets merged across studies (although they help). In some of our own studies, we have now started collecting many data points from a single person or dyad (in this case, couples in romantic relationships). We are currently, for example, collecting temperature data from couples every second for three consecutive days.

When trying to establish reliable phenomena from data, the first step is the realization that one is working towards generating formal, testable hypotheses, developing what are called "severe tests" (Popper, 1962). The only way corroboration can aid in building a theory comes from very risky predictions that could falsify the theory. That is why we are moving toward stating predictions in a very precise way (e.g., "if people are asked to think about their loved ones their peripheral body temperature should rise by at least 0.5 °C"). Another goal we have at the moment is to include some other conditions in our hypotheses (e.g., "if people are asked to think about their loved ones their peripheral body temperature should rise by at least 0.5 °C and this effect will be immediate and will last for 1.5 min" or "if people are asked to think about their loved ones their peripheral body temperature should rise by at least 0.5 °C; this effect should be twice as large for people scoring three on attachment avoidance as opposed to those scoring five on attachment avoidance").

Going from exploration to a testable hypothesis occurs in multiple stages (also see Szabelska et al., 2020). Before collecting data, it is useful to pick variables that ***may*** be relevant for one's models and it is wise to be over inclusive during this stage (e.g., IJzerman et al., 2018). After data collection and before starting one's exploratory data

analysis, it is important to set aside a portion of the data for confirmatory purposes (where analyses are only performed once). A rule of thumb that is often used (but not well-substantiated) is to rely on 2/3 of the data for exploration and the remaining 1/3 for confirmation (before splitting, it is useful to do a power analysis for the confirmatory set with a minimum effect size of interest to ensure the confirmatory—or hold-out—set is large enough; see Wittmann et al., 2020).

In the exploratory phase, the researcher can get familiar with the data, build or reinforce (or undermine) intuitions, check for extreme values, check if there are any misleading patterns, check if our previous theoretical assumptions and expectations are initially verified and try to refine a model of the phenomenon with these preliminary examinations. More importantly, choosing necessary variables and building (theoretical and statistical) models takes place during exploratory analyses. This is also the time to build many models, iteratively fine-tune their parameters, and pick the one that seems to be the best performing one, both from a statistical as well as theoretical point of view (e.g., while one should pick the best fitting model, it is also important to attend to the causal relationships one proposes for one's theory).

At the exploratory stage, one can also try out various statistical approaches. Perhaps the most popular approach in exploratory research is Exploratory Factor Analysis (EFA). Its premise is to probe for latent variables that can be a common, underlying feature in various phenomena. For an EFA, the researcher needs to decide on a sample size (to achieve desired power), how to determine the number of factors, and how to assess the fit of the model. In a recent project, we used both EFA and a type of supervised machine learning (conditional random forests) to discover the best model from the data (Wittmann et al., 2020). In that particular case, we extracted all possible combinations from the data, generating a prediction, for example, that in a sample of French students, attachment avoidance relates to the desire to socially thermoregulate in the following way (controlled for by sex): Avoidance = 4.50 − 0.56 Social Thermoregulation + 0.07 Sex. At present, we ***did*** identify core theoretical principles that we thought we should test, but our models ***do*** mainly remain statistical models, where

the strength of the causal inference is unclear, or at best, modest. Once our measures are better defined, we are looking to move towards either agent-based or other, more complex, mathematical models to make riskier causal predictions.

From Statistical Models to Proper Theories

At this stage, we have merely established robust phenomena and cared mostly about prediction, not explanation (Yarkoni & Westfall, 2017). But given the existing problems in the literature, it is fair to say that we need to establish explananda before we can identify explanans. Establishing the explananda will allow us to move forward to establishing causality in our theoretical models, while being modest at the time of establishing the explananda. Establishing robust phenomena will consist of asking what the population of interest is, what the population size is (fixed or dynamic), what the distribution of initial traits or behaviors is, how individuals within the population make decisions, and what the spatial or network structure of our population is (Smaldino, 2020a). Formalizing one's predictions in such a way then allows for creating very precise experimental tests in very precise ways that allow for causal inference.

When making more precise causal predictions, one should aim to test just the winner based on conclusions from the exploratory phase. There is no room for "what happens if..." anymore; for example, there is no room to wonder what happens to people's peripheral body temperature if they are asked to think about their loved ones. The confirmatory phase is the time of testing predictions in the form "if A, then B" (for example, "if people are asked to think about their loved ones their peripheral body temperature will rise by 0.5 °C"). Preferably, these predictions should be as precise as possible by generating point predictions and very precise moderators.

We think that the most preferable way to specify one's hypotheses a priori is via a Registered Report (such that even negative results are published), but, at the very least, via a pre-registration on a site like the Open Science Framework. While in an exploratory phase it is desirable to build an analysis plan after seeing the data, it is unacceptable in the confirmatory phase. To verify our predictions, we should have the

analysis plan and code ready before seeing the data to avoid the temptation of adjusting our analysis to the data and results we are hoping to get from the dataset (for templates, see: https://osf.io/q29nf/). It can surely happen that we see an interesting pattern that we had not noticed before or simply that our model is not the most optimal one. It is understandable that one would like to explore new paths, and it should always remain possible to do so. But in case one explores previously unregistered hypotheses, one needs to also adjust the certainty status of one's conclusions.

Of course, relying on such precise predictions often requires an increase in power. It is often necessary to switch from a between-participants design to a within-participants design, and we anticipate that almost always one needs to rely on a "team science model" to collect data from many different sites to have sufficient power and to have a varied sample of participants that allows for sufficient generalizability of one's theory (Forscher et al., 2020).

Reaching Appropriate Conclusions

The models we specify also allow for much greater modesty about one's conclusions. As psychologists (ourselves included), we often overgeneralize to populations or stimuli we have not yet tested. In this connection, it is widely known that US psychology primarily relies on US (and to a lesser extent, European) student samples, yet theories are often suggested to apply to all humans (Arnett, 2008; Cheon et al., 2020; Henrich et al., 2010). Epistemic humility about one's conclusions is an important virtue for theory development. In the social thermoregulation literature from 2009—2017, for example, 131 of the variables measured were done so in the USA, 20 in China, 3 in Poland, 4 in Singapore, 14 in Israel, 30 in Germany, 10 in South Korea, 35 in the Netherlands, 30 in Hong Kong, 6 in Japan, 9 in the UK, 3 in New Zealand, 13 in Canada, 2 in Switzerland, 5 in Italy, and 4 in a multi-country setting (e.g., IJzerman et al., 2018b; see Fig. 15.1).



Fig. 15.1 Countries in which social thermoregulation studies have been conducted

This collection of Western, Educated, Industrialized, Rich and Democratic (WEIRD) countries (that all use temperature metaphors mixing warmth and affection: Koptjesvkaja-Tamm, 2015) severely limits the generalizability of our model. A useful tool that we have started applying to force epistemic humility onto ourselves is Simons et al.'s (2014) Constraints on Generality section. By defining the limits of one's theory (or by being explicit about one's prediction about generalization), one builds a much clearer formal theory.

Relatedly, IJzerman et al. (2020b) propose an evidence framework for the application of psychological science to societal issues. The ***Evidence Readiness Levels*** identified by IJzerman et al. (2020b: evaluating validity of measures, comparing candidate solutions, establishing causal inference, and testing in a variety of environments) all map onto the issues we discussed in this chapter. Explicitly identifying how "theory ready" models are will go a long way to identify reliable and tested theoretical mechanisms.

Conclusions

In this chapter, we have described findings on social thermoregulation and what the problems are in the literature. Despite the fact that there are many problems (i.e., findings being underpowered, measures often being insufficiently validated), we have sufficient confidence in the literature to continue building towards a formal theory. Indeed, several pre-registrations show sufficient support for the idea and a number of reports also show seemingly robust relationships through techniques like supervised machine learning. However, at present, the best we have is a weak verbal theory. When we started to draft this chapter, we tried to describe the literature from a specific theoretical point of view, such as the radical embodiment point of view (as we had various authors involved that discussed the work from different perspectives). However, we discovered we could not argue strongly in favor of one theoretical perspective over other ones. Truthfully, none of us felt comfortable enough to take a strong position because strong, severe tests that support one theory over others are simply lacking. We strongly suspect, however, that within the social embodiment literature we are not alone. We hope that this chapter contributes to more reliable theory formation across our field. Establishing reliable ways to measure the phenomena of interest and that they exist is vital before being able to distinguish competing theoretical perspectives against each other.

Acknowledgements

We thank the editors, Iris van Rooij and Paul Smaldino, for their helpful feedback. Any remaining errors are the authors' responsibility.

Ethics Declaration

Conflict of interest—Hans IJzerman wrote a popular science book on social thermoregulation: IJzerman, H. (2021). ***Heartwarming: How our inner thermostat made us human***. New York, NY: W. W. Norton & Company.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_16

16. The 4Es and the 4As (Affect, Agency, Affordance, Autonomy) in the Meshed Architecture of Social Cognition

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Abstract
This chapter builds on the model of a meshed architecture introduced by (Christensen et al., Mind & Language 31:37–66, 2016) to explain skilled performance. The model, as it has been developed, explains how higher-order cognitive elements are integrated with lower-order, automatic motoric processes during performance, mapping out a vertical-hierarchical integration. A more complex, enhanced model of the meshed architecture is developed here, introducing (1) intrinsic control features which are not reducible to automatic processes, (2) affective factors that modulate both cognitive and motoric processes, and (3) a horizontal integration of environmental, social, and cultural-normative factors, consistent with 4E (embodied, embedded, extended, and enactive) approaches in cognitive science. This enhanced model is then applied to the analysis of social cognition, understood as a social interactive performance, in order to show how

we can think of the meshing of various semiotic factors in communicative and social interactions.

Keywords Social Cognition – Expertise – Embodiment – Meshed Architecture

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In studies of social cognition, everyday embodied social interaction is sometimes compared to a dance or musical performance (e.g., De Jaegher et al., 2010; Gallotti et al., 2017; van Alphen, 2014). In this chapter, I intend to broaden this metaphor and consider social cognition as a form of embodied performance, where performance includes the type of skilled and practiced actions that one finds in both athletics and the performing arts. This approach helps to clarify the complicated relations between what is now typically called "4E" (embodied, embedded, extended, and enactive) cognition (Newen et al., 2018)[1] and what I will call the "4As"—affect, agency, affordance, and autonomy. To show how these various aspects come to be integrated in social interaction, I will build on the notion of a meshed architecture introduced by Christensen et al. (2016) to explain skilled performance. This type of cognitive architecture is meant to explain how cognitive factors such as attention, reflection, and judgment integrate with (or mesh with) motor control processes. In contrast to interpretations that explain this meshing as a vertical (top-down ***versus*** bottom-up) hierarchical integration between higher-order cognitive control processes and lower-order, automatic perceptual-motor processes, all of which are contained within the individual agent, I will suggest that the meshed architecture is further characterized by a horizontal integration of external (environmental, social, and normative) factors.

Social Cognition as Performance

It is frequently said that social interactive processes involve a musicality (e.g., Gallotti et al., 2017; Schiavio & De Jaegher, 2017; Trevarthen, 1999, 2015), and, in some cases, social interaction has been compared to dance. For example, to the extent that in the intersubjective context, interaction has an autonomy that goes beyond

what the participating individuals bring to the process, much like dancing the tango, it is not reducible to a set of mechanisms contained within the individual; like the tango, social interaction takes (at least) two embodied individuals who are dynamically coupled in the right way (De Jaegher et al., 2010; van Alphen, 2014). Building on this metaphor, the tango has a signi cant normative structure (a speci c set of movements that make it tango, and which, if violated, makes it something other than tango), which captures the way interaction can sometimes work in instituted social practices. One can also think that less formal interactions between partners are more like free-form dance. In either case, the enactivist idea is that continuous dynamical movements between synchronized, desynchronized, and in-between states drive the process of communicative and social interaction (De Jaegher, 2009; De Jaegher et al., 2010). Attunement, loss of attunement, and re-established attunement maintain both differentiation and connection between individual agents. These processes result in the enactment of meaning that goes beyond what each individual qua individual can bring to the process. In some respects, however, the connection with music and dance goes beyond metaphor since, in many cases, dance itself is a form of intersubjective interaction and can be studied as such (Glowinski et al., 2017; Ravn, 2016); and one can use dance as a way of studying intersubjective interaction (Sevdalis & Keller, 2011). There are also close connections between intersubjective empathy and musical (esthetic) empathy (van der Schyff & Krueger, 2019). Accordingly, it may be fruitful to look at the processes involved in musical and dance performance, but also in other forms of performance, to clarify the role of interaction in social cognition.

This may help to address one worry about embodied-enactive approaches that emphasize interaction—namely, that cognition itself seems to be left out of the picture of social cognition. The concept of 4E cognition or the embodied mind, of course, does not support the traditional Cartesian or cognitivist conception of cognition, but this does not mean that social interaction is mindless. By examining the role of cognition in skilled performance, we may be able to get some clarity on how to understand cognition in embodied interaction.

We start, however, with a view that suggests little role for cognition in performance. Hubert Dreyfus (2005, 2007), in his well-known

analysis of expertise, has argued that expert performance involves being in the flow, but requires no reflective cognition—something that would be disruptive of performance. For instance, he regards subjectivity as a lingering ghost of the mental, and denies that there is any awareness in absorbed coping (2007, p. 373). As long as things go smoothly, there is no need for self-consciousness—consciousness is only called into action when the agent detects something going wrong (2007, p. 377; see Dreyfus, 2005). At the extreme, this view suggests that expert performance is simply a mindless being in the flow.

In contrast, studies of athletics, dance, theater, and musical performance suggest that performance is not mindless. For example, Sutton et al. (2011) develop a mindful conception of expert skilled performance. It is not just trained habit that allows an expert player of cricket or baseball to hit a hard fastball (which may be traveling at 140 km/h). In order to hit the ball with precision to a particular part of the field, the batter must draw on current context and the conditions that are relevant to the game. Her performance is "fast enough to be a reflex, yet it is perfectly context-sensitive. This kind of context-sensitivity requires some forms of mindedness – [an] interpenetration of thought and action exemplified in open skills" (Sutton et al., 2011, p. 80). The expert batter is not on automatic pilot—she has trained up her body-schematic control of movement, but what she needs to do in the context of a game cannot be automatic. Batting skill within the context of a game, for example, involves some mindful strategic sense of where the batter will hit the ball in any particular instance:

> Skill is not a matter of bypassing explicit thought, to let habitual actions run entirely on their own, but of building and accessing flexible links between knowing and doing. The forms of thinking and remembering which can, in some circumstances, reach in to animate the subtle kinaesthetic mechanisms of skilled performance must themselves be redescribed as active and dynamic. (Sutton et al., 2011, p. 95)

Automatic control has limited ability to cope with variability; skill and innovative performance requires flexibility. In this connection, the expert batter is aware of the specifics of the situation and is capable of

on-the-fly, explicit, considered awareness, which allows for strategic decision making in the flow of performance. This includes elective "target control for some features, such as goal, one or more parameters of execution, like timing, force, a variation in the sequence, and so on" (Christensen et al., 2016, p. 50). In this respect, "expert performers precisely counteract automaticity, because it limits their ability to make specific adjustments on the fly…Just because skillful action is usually pre-reflective, it does not have to be mindless" (Sutton et al., 2011, p. 95).

Two questions arise from this analysis. First, what precisely is meant by explicit thinking and remembering? On an embodied cognition approach, thought is not necessarily equated with an inner process working behind practical skill, but may be an intrinsic and worldly aspect of our real-time engagement in complex physical and cultural activities. In either case, however, a second question emerges: how precisely does thought "reach in" to the basic body-schematic (kinesthetic) processes of action? Answers to these questions, I will argue, are relevant not only to performance, but also to social interaction.

Christensen et al. (2016) offer a helpful answer to the second question—a model of a meshed architecture which integrates perceptual and cognitive elements with body-schematic control. On this view, performance is neither fully automatic nor fully cognitive. Rather, "cognitive control reduces during skill learning as automatic control comes to play an increasing role, but cognitive control continues to make a substantial positive contribution at advanced levels of skill" (2016, p. 41). The authors note, however, that it remains unclear how hybrid control operates. They outline two possibilities: (1) an ***autonomous*** functioning that describes "abbreviated forms" of conscious reasoning during performance—e.g., a quick decision on strategy that then allows automatic processes to take over the execution of action (for this model, see Beilock & Gray, 2007; Papineau, 2013). The Christensen et al. preference is for (2) a ***meshed*** functioning which involves "a broadly hierarchical division of control responsibilities, with cognitive control usually focused on strategic aspects of performance and automatic processes more concerned with implementation" (2016, p. 43). At first glance, this seems similar to the

autonomous approach, but the authors specify that there is a close integration so that cognition directly influences motor control in some cases. This integration is mediated by "situation awareness" that does not require explicit inferences, but rather is an awareness that is constructed over time with the help of attentional control. The cognition involved in this process is not at the high-level of prior intention, but closer to an intention-in-action that specifies an action in context, directly shaping the action.

Christensen et al. (2016) explore the detailed example of driving an automobile in order to work out differences between autonomous functioning and meshed functioning. The meshed architecture model is a promising one, and it can apply more generally to many different forms of performance, including dance and musical performance. I will argue that it can also be applied to intersubjective interaction. But first, it will be helpful to see how it works in the case of dance and musical performance.

Vertical Integration of the Cognitive and Motoric

Different interpretations of a meshed architecture are possible, depending on how we answer the first question about how to understand explicit thinking and remembering in some of the above descriptions. In some theorists, we can find an overly cognitive interpretation. For example, in her discussion of meshed architecture in the context of theatrical performance, Evelyn Tribble (2016) cites Robert Cohen's description of the actor's "preparatory thinking as she readies herself for the role, and in-performance thinking, which, in an ideal situation, is 'aligned' with the [performer's] action" (Cohen, 2013, p. 33). According to Cohen, when the actor's thinking is "properly aligned, her tasks are integrated" (2013, p. 16). As Tribble indicates, Cohen describes a top-down process, where low-order processes of embodied coping are modified by higher-order, reflective cognitive processes.[2] This would be a strictly vertical integration between a low-order flow of embodied coping (ala Dreyfus), and higher-order,

reflective cognitive aspects, with perhaps different degrees of integration between the higher and lower processes.

In studies of dance performance, the philosopher Barbara Montero (2010, 2015), drawing on her own experience as a professional ballet-dancer, likewise rejects the idea that expert performance somehow is effortless or thoughtless. In contrast to Dreyfus, she argues that although certain types of bodily awareness may interfere with well-developed skills, it is typically not detrimental to the skills of expert athletes or performing artists. Although Montero allows for the possibility that the performer's awareness stays prereflective in the case of dance or musical performance, she also thinks that optimal performance often coincides with thoughtful performance. Montero points to qualitative studies in athletics in which a more detailed type of conscious monitoring improves performance (2015, p. 90).

Richard Shusterman (2008), in a similar fashion, identifies two types of explicit body-consciousness involved in such an integration: prereflective conscious somatic perception and reflective somatic perception with explicit awareness. The first includes a visual or proprioceptive sense of one's body parts, their relations with other body parts, posture, and with objects in the environment. One can also be aware of breathing, or of tensions in one's body. In the second type of explicit reflective consciousness, "we are not only conscious of what we perceive as an explicit object of awareness but we are also mindfully conscious of this focused consciousness as we monitor our awareness of the object of our awareness through its representation in our consciousness" (p. 55). That is, we are self-consciously aware of our own perceptual monitoring.

The idea that there may be different degrees of vertical integration in the meshed architecture of performance may depend on just how one answers the first question about the nature of thoughtful or mindful performance. The answer shifts between a phenomenology that involves a reflective monitoring, and one that involves mostly prereflective awareness. Phenomenologists conceive of the latter as a self-awareness that does not take the body as an intentional object, but rather involves a "performative awareness…that provides a sense that one is moving or doing something, not in terms that are explicitly about body parts, but in terms closer to the goal of the action"

(Gallagher, 2005, p. 73). Dorothée Legrand (2007) distinguishes this kind of performative self-awareness from opaque and transparent awareness. By opaque, she means a thematic, reflective awareness that objectifies the body—something that would characterize a novice performance when someone is learning to move in dance or music. By transparent, she means that the body is experienced nonthematically, prereflectively and as an aspect of the acting subject—as in everyday walking. In the context of dance, Legrand describes a more subtle performative self-awareness as follows: "while dancing [a dancer] is intensively attending to [his body]. But he is not attending to it reflectively as an object. Rather, his [prereflective] awareness of his body as subject is heightened" (2007, p. 512; see Legrand & Ravn, 2007). The expert dancer can put this subjective character of experience "at the front" of his experience without turning experience or action or the body into an explicit intentional object (Legrand, 2007, p. 512). Toner et al. (2016) summarize a number of insights from this phenomenological perspective as it applies to expert performance and describe a "dynamic interplay" between prereflective and reflective processes (2016, p. 311).

In these various accounts, it seems that what Christensen et al. (2016) call situated awareness is a matter of degree, ranging from thoughtful, reflective consciousness, to a thin performative prereflective awareness, with different gradations in between, allowing for such variations as selective target control, conscious monitoring, a sense of one's rightly configured body, performative awareness, and prereflective awareness. The phenomenology of performance may thus be complex and varied. Performers can shift across a full register, from explicit conscious control to implicit prereflective consciousness, to automatic and spontaneous body-schematic processes, improvising in some cases to adjust their attunement to changing conditions.

I conclude this section with two notes about the foregoing discussion. First, on some of these accounts, one might think that the integration processes involved in situated awareness are primarily top-down—variations of control introduced by thoughtful processes. One important clarification is that the integration processes can work from the bottom-up. Practiced and habitual movements (which are not straightforwardly or necessarily automatic) play an important role in

dance and performance more generally. Variations in heedful and targeted (attentive, perceptual) awareness are constrained and enabled by a consolidation of fine, detailed motor control (body-schematic) processes (which are not perfectly general or automatic, but attuned to the specifics of the situation). Second, if these accounts of the meshed architecture in performance focus on variations in vertical integration of cognition and movement, there is some evidence that the mesh is even more complex and that we need to consider a form of horizontal integration.

Intrinsic Control, Affectivity, and Horizontal Meshing

We can get a better idea of both the constraints imposed by bottom-up processes, and horizontal integration, by considering an example of musical performance that will bring us directly back to the topic of social cognition. Høffding's (2019) study of the Danish String Quartet provides some evidence that the meshed architecture involves both vertical and horizontal integration. Thus, for example, on the vertical line, we can find similar considerations about the role of thoughtful performance ranging from explicit reflective thinking to prereflective awareness, and in some cases, a form of deep absorption where close to automatic processes of the body schema do most of the work. Along this line, Høffding and Satne (2019) interpret the notion of a meshed architecture as focused on mediating processes between the all-or-nothing "automatic" versus "full cognitive" control.

Høffding's (2019) analysis helps to anchor the phenomenology of performance in deeper structures, those prenoetic processes that occur below the surface—body-schematic processes that are attuned by practice and that allow the performer to forget about the complex motor details of performance. Such processes provide the freedom to pay mindful attention to relevant surrounding factors—to heedfully focus on selective target control. Perfectly specific and highly dynamical body-schematic processes facilitate movement in particular situations. There are, in fact, lots of moving parts that require controlled integration, across varying timescales, to align with a particular action intention or goal. This is what I call ***intrinsic control***—

control processes that are not introduced by higher-order cognitive factors, but are built into motoric operations. Body-schematic processes are not, as Jason Stanley (2011) claims, "perfectly general," but rather perfectly speciﬁc and include an "enormous number (which often reaches three ﬁgures) of degrees of freedom" (Bernstein, 1984), as well as a complex temporal organization involving anticipatory processes across skeletal geometry, kinematic phase constraints, muscular geometry, and the dynamics that characterize the relationship between kinematics and geometry (Berthoz, 2000; Gallagher & Aguda, 2020).[3] Such complexity allows for precise adjustments to speciﬁc differences in situation.

Body-schematic processes are not fully automatic, either. Practice within such constraints may tune motoric organization to the point where it can become habitual—close to automatic, or automatic in some aspects, but not fully automatic (see Fitts & Posner, 1967; Jonides et al., 1985; and Logan, 1985). Kinematic analysis of classical dancers shows that practice can modify degrees of freedom by combining movements of related joints into synergetic units, thereby reducing control demand, as reﬂected in neural processes (Thullier & Moufti, 2004). Merleau-Ponty argues that a habit is developed in practice when the body "acquires the power of responding with a certain type of solution to a certain form of situation" (2012, p. 143). Instead of blind repetition, habit is an open and adaptive way in which the body learns to cope with familiar or unfamiliar situations. Dewey (1922) likewise distinguishes between intelligent and routine habit. He rejects the idea that repetition is essential to intelligent habit, which should be understood as a sensitivity to the situation and as a way of responding to it (1922, p. 42).

Accordingly, performance involves not simply a top-down integration of cognition constraining automatic processes. Motoric processes, in the case of expert performance, are neither general nor characterized by automaticity, but are already context-sensitive, smart, open, and adaptive. Importantly, just such intrinsic adaptive processes may elicit, or shape, or enable the cognitive elements required for performance. In this sense, in the meshed system of embodied performance, control may be bottom-up, driven by the intrinsic

(sometimes habitual) processes of body-schematic functions that are attuned to or embedded in specific situations.

Høffding's (2019) analysis of musical performance highlights these body-schematic processes, but also shows that in addition to the reciprocal vertical integration of cognition and body-schematic attunement, other factors are important. The other factors include affect (still on the vertical axis), but also the music itself, and intersubjectivity—i.e., the other players (Høffding, 2019; Høffding & Satne, 2019; Salice et al., 2017), which, I suggest, define a horizontal axis that extends out to include social factors and normative constraints associated with cultural practices.[4]

Affectivity in the broadest sense includes emotion processes, but also more general and basic bodily states such as hunger, fatigue, pain. Affect, or what Michelle Maise (2018) calls "affective framing," shapes our ability to cope with the surrounding world (Colombetti, 2014; Ratcliffe, 2012). Affect may work differently in different types of skilled actions, for example, in various athletic performances and in the different performing arts. The important differences may have to do with the way that affective factors are integrated with motoric/agentive factors. Affect/emotion may involve expressive movement, as in dance—movement that is like gesture and language, but nonetheless depends on motor control, although it goes beyond simple motor control or instrumental action. There are different mixes or integrations of expressive and instrumental movements in athletics, dance, or musical performance. It is not that the body schema carries on independently, delivering technically proficient movement, to which we then add an expressive style motivated by specific emotions that may be occasion-relative. Affective processes directly shape body-schematic processes—slowing down or speeding up such processes, for example, or leading to the adoption of certain initial postures that may influence the performance. Affect and body-schematic processes are integrated—still part of the vertical mesh in expert performance—but also allow for an integrated attunement to targets and environmental features in the performance situation.

Once we start to think about the music itself, and the other performers, for example, we come to an enriched conception of the meshed architecture that incorporates a form of horizontal

integration. In this respect, ecological, normative, cultural, and intersubjective aspects of the physical and social environment, including physical and social affordances, play a role (Fig. 16.1).

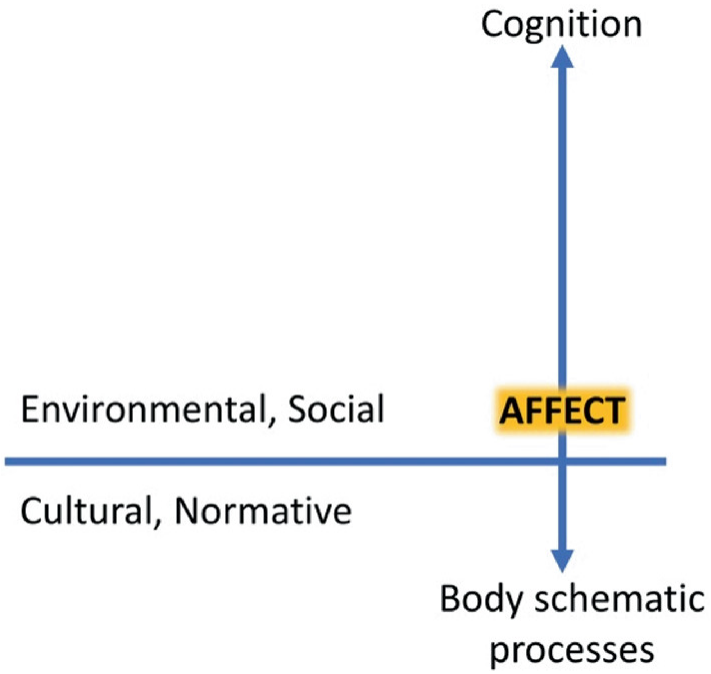


Fig. 16.1 Vertical and horizontal axes of the meshed architecture

As one engages in a particular performance, one's agency (or sense of agency) may be modulated by affective experience but also by the quality and quantity of affordances available. In Høffding's (2019) analysis, the musical instruments, the performance space, and the music itself shape the musical performance. The style of music, whether one is playing from a score, whether improvisation occurs—these factors define different dynamics. All of this, in line with embodied-enactive conceptions of action and experience, helps to show that what makes performance what it ***is*** is not entirely inside the performer, whether she be musician, dancer, athlete, or expert in everyday affairs. When, for example, the performer "can 'feel' that her motor system has the right configuration" (Christensen et al., 2013, 59), this configuration is just the right one to mesh with the specifics of the performer's physical and social environment. Neither body-schematic processes nor affective processes are isolated from the agent's environment; rather, they are attuned to both stabilities and variations in extensive, environmental factors, including other agents.

Accordingly, the environment where performance takes place is not only physical, but also socially, culturally, and normatively defined. Performance in a concert hall or in a church may be quite different from performance in a stadium or a pub or in the open air. That we are playing music with others, and who those others are, how skilled they are, and how long we have interacted with them—all of these factors can impact performance (Clarke et al., 2015). In some cases, one requires what Høffding calls "joint musical attention" (2019, p. 212), a shared sense of the music, a kind of entrainment and sensorimotor synchronization with the other players that produce a joint musical experience that approaches Merleau-Ponty's notion of intercorporeity. The inclusion of the other players expands the scope of attention and the sense of agency to include a "we-intentionality: a musical intercorporeity" (Høffding, 2019, p. 217).

The meshing of the horizontal and vertical axes may take the form of "joint body schemas" in practices that have been shown to extend an individual's peripersonal space to include the other person, evidenced in changes to neuronal and behavioral processes (Soliman & Glenberg, 2014). As Soliman and Glenberg show, these body-schematic effects are not simply modulated top-down by cultural practices, but rather, such social and cultural factors are incorporated into body-schematic processes which, in turn, express them in motoric performance. Performance thus involves distributed and temporally extended processes that includes all relevant variables—embodied, ecological, intersubjective/social, and cultural (see Farina & Cei, 2019 for a review of such issues applied to expert performance more generally). These are not the accomplishments of narrow processes taking place just in-the-head, or strictly on a vertical axis, but are processes that extend into the world, meshed with the structures of our intercorporeal and material engagements.[5]

The 4As and the Relational Ontology of Intersubjective Interaction

The analyses of dance and musical performance, based on both empirical and phenomenological research, provide a rich and complex

picture that can lead back, as we have seen in Høffding's (2019) analysis, to questions about intersubjective interaction. There is no question here of providing a complete or exhaustive point-for-point mapping of social cognition onto the meshed architecture (and its variations) that characterize dance or musical performance. My intention in this final section is simply to apply the general idea of a meshed architecture, drawn from the analysis of performance, to social cognition (for its relevance to situated cognition more generally, see Gallagher & Varga, 2020). As a way of organizing this task and highlighting some specific points, I will make use of what I call the 4As: agency, affect, affordance, and autonomy. These are dimensions of human existence that are closely interconnected in social interaction. Affective changes can modulate both my agency and my field of affordances. Agency and affordances may co-vary: e.g., more affordances often mean more possible actions. A decline in agency and constriction of affordances can easily lead to a decline in autonomy.[6] These dimensions are directly in play in intersubjective interactions, which are often empathically affective, often creative of new affordances, and often constraining or enabling of actions. Importantly, in this regard, we can understand autonomy as relational. Mackenzie and Stoljar (2000) succinctly summarize these connections:

> [P]ersons are socially embedded and...agents' identities are formed within the context of social relationships and shaped by a complex of intersecting social determinants, such as race, class, gender, and ethnicity...[A]n analysis of the characteristics and capacities of the self cannot be adequately undertaken without attention to the rich and complex social and historical contexts in which agents are embedded;...[we] need to think of autonomy as a characteristic of agents who are emotional, embodied, desiring, creative, and feeling, as well as rational, creatures (Mackenzie & Stoljar, 2000, p. 4).

Interacting with others, accompanied by the various extended arrangements of the surrounding world, can enhance an individual's agency and autonomy by providing a greater quantity or quality of affordances—or it can impoverish agency and autonomy. All of these

factors are relational. Interpretations of the Gibsonian notion of affordance, for example, emphasize the relational character of affordances. Affordances are not objectively out there in the environment—they depend on the agent's skill level, and can be minimized or maximized by an agent's affective condition. The relational notion of affordance and the notion of relational autonomy help to define the character of the mesh or integration of factors we have been describing. Let us see how this works in intersubjective interaction.

Social cognition processes are at the very least dyadic; they involve two or more individuals who interactively engage with one another in dynamic ways that lead to social understanding or misunderstanding, joint attention and joint action, cooperation or competition in contexts that are pragmatic and normative. Evidence for this kind of interaction theory can be found in developmental psychology and in ethnographic studies. Developmentally, embodied intersubjective interaction involves two sets of processes or abilities.

- Primary intersubjectivity (starting from birth)—Affective processes and sensory-motor abilities, including enactive perceptual capacities in processes of interaction
- Secondary intersubjectivity (starting around 9-months to 1 year of age)—abilities to jointly attend, share agentive contexts and affordances, engage pragmatically, and act ***with*** others.

Primary intersubjectivity puts us into relation with others and allows us to interact with them from the very beginning (Reddy, 2008; Trevarthen, 1979). These capacities are manifested as we engage with others and perceive in their bodily postures, movements, gestures, facial expressions, gaze direction, vocal intonation, etc., what they intend and what they feel. We respond with our own bodily movements, gestures, facial expressions, gaze, etc. On this view, in second-person interactions, the "mind" of the other is given and manifest in the other person's embodied comportment. Accordingly, the basis for human interaction and for understanding others can be found already at work in early infancy in embodied practices that reflect sensory-motor, perceptual, and affective processes. Infants already have a sense, from their own self-movement and

proprioception, of what it means to be an experiencing agent.[7] Indeed, "an alert newborn can draw a sympathetic adult into synchronized negotiations of arbitrary action, which can develop in coming weeks and months into a mastery of the rituals and symbols of a germinal culture, long before any words are learned" (Trevarthen, 2011, p. 121).[8]

Primary intersubjectivity can be specified in much more detail. Infants become attuned to the other person's attention; at 2 months, they follow the other's head movements and gaze (Baron-Cohen, 1995; Maurer & Barrera, 1981); they "vocalize and gesture in a way that seems [affectively and temporally] 'tuned' to the vocalizations and gestures of the other person" (Gopnik & Meltzoff, 1997, p. 131). This "attunement" or mutual alignment can be specified in dynamical relations and the integration of the intrinsic temporalities of dyadic movements (Trevarthen, 1999; Trevarthen et al., 2006). At 5–7 months, infants are able to detect correspondences between visual and auditory information that specify the expression of emotions (Hobson, 1993, 2002; Walker, 1982). At 6 months, infants perceive grasping as goal directed. At 10–11 months, infants are able to parse some kinds of continuous action according to intentional boundaries (Baird & Baldwin, 2001; Baldwin & Baird, 2001; Woodward & Sommerville, 2000).

Developmental studies thus show the very early appearance of, and the importance of, affectivity, timing, and coordination in the primary intersubjective context where what matters is the interaction dynamics (Muir, 2002; Murray & Trevarthen, 1985; Nadel et al., 1999; Stormark & Braarud, 2004; Tronick et al., 1978). For this reason, Trevarthen has characterized this early interaction as reflecting a musicality, a kind of "musical activity," especially between mother and child. He points to gestural mimesis, protoconversations, and the sympathetic engagement in rhythmic expressive exchanges in these interactions (e.g., "Babies from 4 or 5 months, attending to their mother's performance, often vocalize in matching synchrony with the intonation of the lengthened syllables of rhyming vowels" [Trevarthen, 2015, e-paragraph 35]). These processes, "regulated by, and regulating, dynamic emotional processes, form the foundations of human intersubjectivity, and of musicality" (Trevarthen, 1999, p. 155; see

Overy & Molnar-Szakacs, 2009 for a view on the neuroscience involved). In infancy:

> animal movements find their purposes and are coordinated by internal rhythm generators or pace-makers that make prospective control possible ... instinctively perceiving "affordances for action on the environment" involves systematic orientation of body parts and their senses with rhythms generated by "loosely coupled oscillators" (Trevarthen, 2015, e-paragraph 17; quoting Nikolai Bernstein).

Trevarthen, along with Stephen Malloch (Malloch & Trevarthen, 2009), used computational measures of musical acoustics to study vocalizations of care-givers interacting with infants in proto-conversational speech, finding universal patterns they called "communicative musicality." Described in this way, this kind of musicality or performance in primary intersubjectivity is clearly bottom-up on the vertical axis, emerging from affective and agentive-motor processes, but importantly, already delineating a horizontal dimension since they are dependent on the presence and actions of others. This horizontal, ecological dimension broadens in secondary intersubjectivity. Sometime during the first year of life, infants build on the person-to-person immediacy of primary intersubjectivity, and enter into ***contexts*** of shared attention—shared situations that are pragmatic and normative—in which they begin to learn how people engage with things, and what those things mean (see Trevarthen & Hubley, 1978). Secondary intersubjectivity emerges in joint attention, when an object or event knowingly becomes a focus for two (or more) people, and their interactions start to have reference to such things (Hobson, 2002, p. 62).

Joint attention thus forms a bridge between primary intersubjectivity and secondary intersubjectivity (Tomasello, 1995). Infants around this time also learn to point and between 9 and 18 months look to the eyes of the other person to help interpret the meaning of an ambiguous event (Phillips et al., 1992; Reddy, 2008). Infants, in contexts of joint attention, are highly responsive to attentional and emotional cues as part of their secondary

intersubjective abilities. Infants often share emotions—e.g., exchange smiles, when playing with a toy in joint attention with another (Messinger & Fogel, 2007). They follow another person's gaze to the appropriate target (Butterworth & Jarrett, 1991) and reference the other's emotional expressions to know whether to approach novel objects (Klinnert et al., 1986; Moses et al., 2001). When infants of 12–18 months see a negative emotional expression by a parent toward a particular toy, they later, and in a different context, avoid playing with that toy (Hornik et al., 1987)—that is, the negative affect removes an affordance. Furthermore, the emotional expressions of one person while watching the action of another (who is showing anger or a neutral facial expression) will influence an 18-month-old infant's inclination to imitate the actions of the second person (Repacholi & Meltzoff, 2007; Repacholi et al., 2006; Repacholi et al., 2008; also Walden & Ogan, 1988). At 18 months, for example, children can comprehend what another person intends to do with an artifact—they recognize an affordance and are able to pursue it. They are able to re-enact to completion the goal-directed behavior that the other agent fails to complete (Meltzoff, 1995; Meltzoff & Brooks, 2001). The understanding demonstrated in such a situation depends on shared attention and the pragmatic and normative context rather than on mindreading.

Just as in dancing the tango, the kinds of interactions that constitute primary and secondary forms of intersubjectivity are not automatic or mechanical procedures, and they should not be thought of as mechanisms or capacities that belong strictly to the individual. Csibra and Gergely (2009) have shown, for example, that the infant is more likely to respond to another person's actions only if that person is attending to the infant. The methodological individualism that defines the quest for underlying mechanisms or individual capacities, and which motivates much of the developmental literature on theory of mind, overlooks the essential contribution of the other agent and the interaction process. Moreover, these forms of primary and secondary intersubjectivity do not disappear after the first year of life. They are not stages that we leave behind, or a set of precursor states "that underpin early intersubjective understanding, and ***make way*** for the development of later theorizing or simulation" (Currie, 2008, p. 212;

emphasis added; see Baron-Cohen, 1991, 1995). Rather, these embodied interactive processes continue to characterize our everyday encounters even as adults. That is, our understanding of others continues to be facilitated by our recognition of facial expressions, gestures, postures, and actions as meaningful.

This continuance of primary and secondary intersubjectivity is evidenced in ethnographic studies of adult social interactions in shared activities, in working together, in communicative practices, and so on. Such analyses show how agents unconsciously coordinate or align their movements, gestures, and speech acts (Goodwin, 2017; Issartel et al., 2007; Kendon, 1990; Lindblom, 2015), entering into synchronized resonance with others, as in a dance, with slight temporal modulations (Gergely, 2001), in either in-phase or phase-delayed rhythmic co-variation (Fuchs & De Jaegher, 2009).

We can see how the vertical and horizontal aspects of interaction form a meshed architecture in Charles Goodwin's (2000) example of an enthnographic study of two young girls playing a game of hopscotch. In this example, there is an interactive meshing of various phenomena that must be considered in order to understand the full encounter. Goodwin marks out the "visible, public deployment of multiple semiotic fields that mutually elaborate each other" (2000, p. 1492). These are varied factors that include, for example: the temporal flow/rhythm of vocal intonation; speech acts and gestures, some of which have a deontic rather than descriptive force; bodily movements and postures; the set of instituted norms involved in the game of hopscotch, i.e., the rules of the game; and deictic reference to a completed action (throwing a marker on one of the squares). As one girl interrupts the game by intentionally moving and standing in the way of the other girl, the bodily orientations of the two girls allow for eye contact and joint attention toward the hopscotch pattern on the ground. The ongoing temporal modifications in those postures create meaning as the encounter unfolds. Hand gestures are integrated with speech, but also with the changing body positions of both girls. One of the girls, by changing position, makes sure that her gestures are visible to the other girl; she thus structures the local environment for social action. "Carla's hand is explicitly positioned in Diana's line of sight… thrusting the gesturing hand toward Diana's face twists Carla's body

into a conﬁguration in which her hand, arm and the upper part of her torso are actually leaning toward Diana" (2000, p. 1498).

If there is an explicit thinking going on in the encounter, it is the kind of thinking that Merleau-Ponty identiﬁes as a pragmatic thinking accomplished by speech, and by gesture, and movement. It is explicit because it is being explicated in the intersubjective interaction. In this regard, the arrangement of the various semiotic resources is important, including the proximity of the gesture to the other girl's face. The closeness of the gesture has meaning, as does its timing ***vis a vis*** the speech act. The gesture grabs the other girl's attention, forcing her to orient to the point being made in what is being said, or to a point of joint attention towards something in the environment. Importantly, this is not a one-way process: The other girl, Diana, is standing on one foot, attempting to ﬁnish her jump through the hopscotch squares, attempting to ignore the challenge made by Carla, and the accusation of cheating. The task is to maintain joint attention, which is broken when the other girl looks away. This looking away is also meaningful and shows that the accomplishment of meaning involves two-way interaction and is not under the control of just one individual.

The communicative process is not conﬁned to vocalization, gesture, and embodied movement, but incorporates elements of the local environment. It's not just making reference to the physical environment -- with glances to the hopscotch square under discussion -- interaction also involves making use of it. Carla stomps her foot on the hopscotch square, in a gesture that hits on three semiotic points: (1) where Diana is looking; which is (2) on the hopscotch square in question; which (3) is precisely the object that Carla is iterating in speech. Reﬂecting the "extended" aspect of the 4Es, this is distributed communication, which builds on material aspects of the environment and the context of the game.

The social understanding involved in this encounter between two agents builds on precisely the complex meshing of what Goodwin calls the semiotic resources and the capacities of primary and secondary intersubjectivity, situated within pragmatic and social contexts. These resources are activated and supplemented in the communicative processes. The physical and social affordances presented by the

pragmatic and social contexts are relational and depend on the possibilities opened up by interaction itself.

Consider, then, beyond the vocalized words, the variety of resources arranged along the vertical and horizontal axes of the meshed architecture, that are being drawn on by the two agents in the interaction context:

On the vertical axis:

- Knowledge of rules, completed actions, person-specific traits, etc.
- Strategic decisions to intervene or to resist (although these are likely not well thought out prior decisions)
- Agency embodied in body-schematic processes
- Affective factors on both sides of the interaction

On the horizontal axis:

- The gestures and facial expressions of the other person
- Their bodily movements, postures, vocal intonation, and proximity
- The other's attention—the means to grab it for joint attention
- Instituted norms (connected with play and the game)
- Social rules, roles, and identities
- The rich material environment with its affordances
- The temporal flow/rhythm of movements that depend on the interaction itself.

One might want to talk about intersubjective alignment here, but one can see from this kind of analysis that such intersubjective interaction is not reducible to a simple set of alignment processes, although it does include such processes. Different authors define alignment differently, for example, equating it with simple matching, imitation, or entrainment, as distinguished from other more intentional coordination processes (e.g., Rothwell et al., 2017). Taking both vertical and horizontal axes into account, however, suggests something more complex, including that there is a broad range of embodied and ecological processes integrated into such events, and that different circumstances (e.g., how structured or unstructured the immediate environment might be) and different intentions elicit different dynamical balances among these processes (e.g., Tollefsen et al., 2013).

One key idea is that, at least ***in some cases,*** interaction itself plays an essential role in constituting social cognition (De Jaegher et al., 2010). In pre-linguistic proto-communication, as much as in later verbal communication, as we listen to or engage with another person, we coordinate our perception-action sequences; our movements are coupled with changes in velocity, direction, and intonation of the movements and utterances of the speaker. Some of the same processes involved in dance and musical performance, in addition to others that depend on context, are involved. Both the developmental and the ethnographic evidences are fully consistent with the phenomenological idea of an emerging shared affective intentionality—what, following Merleau-Ponty (2012), we called "intercorporeity"—which comes to be established between or across the perceiving subject and the perceived other.

The concept of understanding involved in understanding others is both ***pragmatic*** and ***affective***. Pragmatic means that it is a form of "know-how," which on the 4E (specifically enactivist) view means that I understand the other person in terms of my actual or potential interactions with them. I know ***how*** to respond to them. This idea broadens into the notion of social affordance. Affectivity refers to what Hobson (2011) calls our affective engagements with the attitudes of others, a feature of typically developing infants' social relations, at least from the age of about 2 months. In these pragmatic, affective, and hedonic embodied dimensions, saliency and meaning emerge. Grasping, pointing, moving towards, moving away, staying close, nodding, gazing in a certain direction, etc.—all of these things occurring in specific styles (Hobson, 2011)—register, often non-consciously, as inherently meaningful aspects of the interaction (Goodwin, 2000).

In the enactivist perspective, as embodied agents, we do not passively receive information from our environment and then create internal representations of the world in our heads; rather, we actively and affectively participate in the generation of the shared meaning we experience, the result of pragmatic and dynamical interchanges between agent and environment (Gallagher, 2017; Varela et al., 1991). The interaction itself contributes something that is not reducible to the actions of the individuals involved (Gibbs, 2001). On this view,

autonomy is relational. One's interaction with others can limit or enable actions, can create or destroy affordances, can reinforce the autonomy of participants, or undermine it.

Conclusion

As I indicated, my intention was not to provide a complete or detailed mapping of social cognition onto the meshed architecture that one can find in musical and dance performances, but simply to use this idea to sketch an approach that shows that the integration is not simply hierarchical, nor is it limited to a vertical mesh between higher-order cognitive control processes and lower-order, automatic perceptual-motor processes. Rather, it is further complicated by affectivity and by the horizontal integration of environmental, social, and normative factors—a set of semiotic resources that shape our social interactions and understandings. Viewing social cognition as in some respects similar to the performance of skilled and practiced actions, involving a meshed architecture, I suggest, helps to clarify the complicated relations between the 4Es and the 4As as they are integrated in social interaction.

Notes

1. "4E" is meant to be an inclusive term signifying a number of different views that continue to be under debate in an already large and expanding literature. Each of the 4Es marks a piece of contested ground. Embodied cognition has been characterized as either weak (i.e., more neurocentric) or strong (i.e., including extra-neural aspects of embodiment); embedded cognition is variously characterized as involving situated, distributed, ecological aspects, as well as phylogenetic considerations about niche construction; extended cognition is framed in different versions (or "waves") of the extended mind hypothesis, or in material engagement theory; and enactive cognition distinguishes between a sensory-motor contingency approach, autopoietic theory, and radical enactivism. For a review of these different approaches, see Gallagher (2011, 2018a). My own view, which combines several of these approaches into a coherent integrated

theory, is strongly embodied, radically enactive, third-wave (non-representationally) extended, with significant input from ecological psychology (Gallagher, 2017).

2. Tribble favors a more extended mind approach to the acting process (see Tribble, 2011); for more on the phenomenology of acting, see Gallagher and Gallagher (2020); and Garner (2019).

3. Here is a more recent description: "The hand has a very complex anatomical structure. Functionally, movements of the hand require a coordinated interplay of the 39 intrinsic and extrinsic muscles acting on 18 joints. Among all the joints of the hand, of particular importance is the carpometacarpal joint of the thumb. This joint is of a saddle type and its immense significance for the hand function emanates from the extra mobility this joint is endowed with, resulting in the opposition of the thumb to the other fingers. The plethora of bones, joints, and muscles of which the hand is constituted gives to this structure amazing biomechanical complexity. From the kinematic perspective, the hand has over 20 degrees of freedom" (Raos et al., 2006, p. 709).

4. Similar things can be said about dance—the dance itself (e.g., whether structured or unstructured), and different dance partners can put varying demands on both motor control and cognitive (e.g., memory) tasks (see Bläsing et al., 2012 for review).

5. There is an important philosophical issue lurking in the background here. This is the so-called causal-coupling versus constitution debate concerning the "boundary' of the mind and whether the various factors under discussion are merely causal factors or actually constitute the mind (see e.g., Adams & Aizawa, 2001). It would take us too far afield to address it explicitly, and for our purposes, we can bracket the metaphysical issues involved. It is sufficient (for purposes of explicating this model and finding it useful) to acknowledge that the various factors involved in the meshed architecture are at least causal contributories to the performance process without making the stronger claim that their dynamical integration constitutes performance or social cognition. For a defense of the stronger claim, however, see Gallagher (2018a,

2018b).

6. In the case of depression, for example, disturbances in affect, including basic feelings of fatigue, lead to a flattened field of affordances and decreased sense of agency. See, for example, de Haan (2020, p. 210); Fuchs (2005).

7. Infants respond, in the interactive mode, to certain kinds of entities (but not to all entities) in the environment—that is, they are able to distinguish between inanimate objects and agents, and they respond to other agents. They can respond, for example, in a distinctive way to human faces—that is, in a way that they do not respond to other objects (Johnson, 2000; Johnson et al., 1998; Legerstee, 1991; Meltzoff & Moore, 1977, 1994). Whether these responses involve imitation (see Nagy et al., 2013; Vincini & Jhang, 2018; Vincini et al., 2017a, 2017b), or perceptual priming, contagion, or simply an arousal response (Anisfeld, 2005; Jones, 2006, 2009; Keven & Akins, 2017; Ray & Heyes, 2011), they draw additional response from the caregiver and this ultimately pulls the infant into interactions with others.

8. Here, and in the following paragraphs, I am endorsing an interactionist approach to social cognition (building on the work of Trevarthen and a number of developmental psychologists). Interaction theory (IT), as a more embodied and enactive approach is usually contrasted with theory theory (TT) and simulation theory (ST), which emphasize the hidden nature of the mind and equate social cognition with theoretical inferences or simulations, respectively. Again, there are a number of issues that distinguish these views. For critical arguments against TT and ST, and in favor of IT, see Gallagher (2020).

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_17

17. Forms and Functions of Affective Synchrony

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Abstract
The reproduction of another individual's emotions in the self—the embodiment of perceived emotions—has been demonstrated to constitute one mechanism for emotional information processing. That is, seeing someone's emotional expressions and using one's own face to make the same expression helps the perceiver represent the emotion of the other. When members of a dyad mimic each other's emotional expressions and by consequence converge in their underlying physiology over time, we say that the dyad has reached a state of affective synchrony. The present chapter brings together recent theorizing and research on physiological and expressive affective synchrony. We propose that affective synchrony serves three interrelated functions: it enables efficient information exchange, allows for interpersonal emotion regulation, and builds social bonds. We review evidence for the contexts in which affective synchrony arises, propose, and evaluate the benefits and costs of achieving these states, and end by suggesting paths for future research in this area.

Keywords Embodiment – Mimicry – Emotion – Synchrony – Physiology

Most of social life boils down to moments of connection. People are usually in the business of getting together, staying together, and pursuing behavioral goals together. They flirt, dance, build, converse, play, and even paddle in double kayaks and ride tandem bicycles. Successful connection is not simple, however. At a basic level, acts of connection involve precise temporal and spatial coordination. Furthermore, people are not social agents that can be programmed to coordinate. During the interaction, real people have emotional responses that sometimes motivate them (e.g., telling them that they do or do not want to continue with action) and serve to regulate their specific behaviors (e.g., telling them whether to approach or avoid something or someone). Thus, in moments of social connection, two or more people monitor, predict, and regulate each other's emotions (e.g., Michael, 2011). How do people accomplish this? How do shared emotions serve to help people get together, stay together, and pursue common goals?

As is the case for the emergence of coordinated motor behavior—joint action (Knoblich et al., 2011)—one mechanism for coordinated emotions is an embodied one. As people monitor each other's emotions, they tend to produce elements of the perceived emotion in themselves. For example, people make the same dynamic facial expressions as those they observe. The act of mimicry, in turn, contributes to a cascading activation of the neural states involved in experiencing other components of the emotion (Wood et al., 2016). When two people's emotions align in form as well as temporal dynamics, we can say that a dyad has come into affective synchrony.

The present chapter is about how and why the components of individuals' emotions become synchronous. We will focus our discussion on the synchrony that can emerge within a dyad, although groups of any size can synchronize, and we occasionally point to relevant findings about group synchrony. We define synchrony as the dynamic and reciprocal adaptation of the timing of corresponding emotional components of members of interacting dyads. The synchronous state may conform to the mathematical description of an oscillator, with a periodic, repeating rhythm, or it may take a different shape. In this chapter, we thus call the state of two people's emotions

coming into embodied temporal and spatial alignment ***affective synchrony***. Behavioral affective synchrony as we define it is somewhat distinct from behavioral ***mimicry*** (Lakin & Chartrand, 2003), which tends to refer to the alignment of emergent categories of behavior (e.g., smiling and head-scratching) rather than continuous measures. Furthermore, we do not say that people "mimic" each other's physiological states, so we use the term "synchrony" throughout this chapter to unite the discussion of behavioral and physiological variables.

We first review evidence for ***physiological*** affective synchrony with a focus on three types of dyads: caretaker–child, romantic partners, and client–therapists. We then make several novel theoretical contributions to the affective synchrony literature. We point out that affective states are not directly transmitted from one person to another—like all forms of information, they require a communication medium. That medium is observable behavior, such as facial expressions, pupillary dilation, and speech. We, therefore, suggest that observable behavioral cues drive physiological synchrony, particularly when those cues become synchronized across people, which we refer to as ***expressive*** affective synchrony. We next integrate evidence in favor of several functions of affective synchrony. These include the proposals that affective synchrony provides (1) a common basis for information processing, (2) an efficient means for finding and meeting challenges and opportunities in the environment, and (3) stronger social connectedness through the generation of feelings of similarity and closeness. We note that affective synchrony sometimes fails to serve these positive functions and can have negative consequences for social interactions and relationships depending upon the emotional context, type of social interaction, and individual characteristics. The negative consequences include the maintenance or escalation of both interpersonal conflict and maladaptive affective responding. We end by suggesting where affective synchrony research might most productively go next.

Physiological Synchrony

Coordinated social interaction involves layers of shared and synchronized physiological processes at multiple timescales (Bietti & Sutton, 2015; Yun et al., 2012). Conversation partners synchronize their pupillary dilation, suggesting the partners' moment-by-moment changes in attention and arousal are linked (Kang & Wheatley, 2017). Partners display synchrony in autonomic nervous state measures, such as heart rate (Mitkidis et al., 2015), breathing (Ferrer & Helm, 2013), skin conductance (Mønster et al., 2016), and cardiac pre-ejection period (West et al., 2017). More global interpersonal neural synchrony occurs during the conversation, in terms of both the timing and content of brain activity, reflecting shared understanding (e.g., Stephens et al., 2010). Some social species even synchronize their daily sleep–wake rhythm (Favreau et al., 2009), suggesting physiological synchrony between bonded individuals can extend even to these slower timescales.

Due to its important roles in promoting bonding and emotion regulation (see "Functions of affective synchrony"), many investigations of physiological affective synchrony examine the synchronization of physiological reactivity in mothers and infants. But classic work investigated physiological synchrony in adults, including between clients and their therapists and romantic couples, as well. In this section, we focus on research that specifically examines synchronization of autonomic nervous system (ANS) processes such as heart rate, electrodermal activity, respiration, and heart rate variability (HRV; for a review of physiological synchrony, see Palumbo et al., 2017). These autonomic signals react to alterations in emotional states and covary in different ways, including conforming to oscillating patterns.

Caretaker–Child Synchrony

Research on mother–infant synchrony was itself inspired by demonstrations that mammalian mothers, through the mechanism of social contact, align their physiological systems with those of their young in order to positively affect the infant's growth (Schanberg et al., 2003) and modulate brain structures implicated in the regulation of stress (Champagne, 2008) and cardiovascular rhythms (Hofer, 1971).

Similarly, human caretakers and infants have been shown to synchronize their cardiac rhythms through the mechanism of touch

(Waters et al., 2017) and also through visual and auditory cues (Feldman, 2007). In a study by Feldman and colleagues (Feldman et al., 2011), cardiac measures of mothers and their 3-month old infants were taken while they engaged in face-to-face interactions, and mothers and infants were also videotaped. Time-series analysis applied to the cardiac output revealed that that mother and infant heart rhythms, but not those of pseudo-dyads, became synchronized with time lags of less than 1 s. Experimenters also coded gaze, expressed affect, and vocal behavior for evidence of synchrony. Analyses relating physiology to these interpersonal behaviors showed that synchrony in maternal and infant heart rhythms increased during periods of affective and vocal covariation, suggesting the emergence of a broader biobehavioral alignment (Atzil et al., 2012).

Water et al. (2014) observed synchronous heart rate in mothers and infants after mothers had experienced a laboratory stressor. The researchers brought mother and infant pairs into the laboratory and temporarily separated the pairs. During the separation, mothers were randomly assigned to a modified Trier Social Stress test in which they received a positive evaluation or negative evaluation during the delivery of a speech and a question and answer period. Mothers in a control condition performed the speech task while alone and received no evaluation. Physiology of mothers was recorded during the task and physiology was recorded in both mother and infant during a reunion period. Results showed that infants' physiological reactivity covaried with mothers' physiological reactivity. Furthermore, the negative-evaluation condition generated higher synchrony in mothers and infants, and this increased over time. Some evidence of synchrony in facilitating social learning was indicated by the finding that the infants of mothers who had been assigned to the two social evaluation conditions later showed more avoidance of strangers in the laboratory (i.e., people who might have stressed the mothers) than infants whose mothers were in the control condition.

Caretaker–child physiological synchrony is observed beyond infancy as well (Main et al., 2016). Woltering et al. (2015) studied the relationship between physiological synchrony and dyadic attunement (or interpersonal responsiveness) in mother–child interactions. Mothers and their 7- to 12-year-old children were invited into the lab

to have discussions of both positive and more conflictual topics while being videotaped. Dyadic attunement was manually coded as a sum of signs of engagement, joint attention, and reciprocity. The heart rate of both members of the dyad was measured and physiological synchrony was estimated using a Structural Heteroscedastic Measurement-Error model, which detects linear relationships between two discrete time series. Higher dyadic attunement was observed in positive discussions (i.e., what would you do if you won the lottery) than in a conflictual discussion (i.e., topics of persisting disagreement). Dyadic attunement, at least in smoothly functioning dyads, thus seems to arise more in interactions characterized by positive emotions. Moreover, dyadic attunement predicted higher physiological synchrony. This was particularly true during a positive interaction that followed the conflictual one, which suggested to the authors that synchrony positively predicts relationship repair.

Romantic Partner Synchrony

Physiological synchrony continues over development and has long been documented in romantic couples. In a series of classic studies, for example, Levenson and Gottman (1983) examined sympathetic nervous system (SNS) synchrony between married couples during social interaction tasks. In one, involving a conversation about a negative topic, couples who had identified themselves as high in marital distress showed higher synchrony in heart rate, skin conductance, pulse transmission time, and somatic movement than did non-distressed couples (Levenson & Gottman, 1983). Neither group showed physiological synchrony during a conversation about events of their day. The authors concluded that couples in distress reciprocate negative affect at the physiological level, whereas non-distressed couples do not. However, significantly more research on synchrony during couples' interactions has been conducted since, which taken together suggests a more complex view of the presence and function of physiological synchrony in married and romantic partners, as discussed further below (Liu et al., 2013; Palumbo et al., 2017; Papp et al., 2013; Saxbe & Repetti, 2010; Timmons et al., 2016).

For instance, Helm et al. (2012) examined the covariation of respiration and heart rate during tasks in which couples gazed into each other's eyes and in which they attempted to mirror each other's

physiology. They modeled the physiological signals using coupled linear oscillator models (e.g., Boker & Nesselroade, 2002). The couple's respiration was found to synchronize during the gaze task and, to some degree, during the imitation task. For heart rate, the findings showed synchrony between couples across both tasks. Similar levels of synchrony were not observed in the patterns of pseudo-dyads that were randomly constructed for comparison, suggesting that only couple's heart rate and respiration are shared during interactions designed to elicit shared emotional arousal. Rather than relating to entrenched conflict, synchrony in these more neutral and positive interactions seems to be associated, as with infants, with dyadic attunement—that is, with a positive connection.

Client–Therapist Synchrony

A similar set of demonstrations have been reported regarding the physiology of clients and therapists during psychotherapy, which is a context in which empathic responding is particularly important (Karvonen et al., 2016; Pascual-Leone, 2009; Ramseyer & Tschacher, 2006, 2011). For instance, Marci et al. (2007) measured skin conductance in psychotherapy clients and their therapists during live clinical encounters. They found that skin conductance alignment during psychotherapy sessions predicted clients' ratings of therapist empathy. Additionally, observer ratings of clips from the sessions indicated that clients and therapists displayed more solidarity and positive regard during moments when their skin conductance concordance was higher.

In a more recent study, Tschacher and Meier (2019) observed significant synchrony between clients and therapists, compared with pseudo-dyads, on multiple physiological indicators including respiration, heart rate, and heart rate variability. Synchrony was assessed by both cross-correlation and concordance (correlation of local slopes) methods, and the level of synchrony positively predicted client reports of the therapeutic alliance.

Expressive Affective Synchrony

How does a dyad achieve the embodied state of physiological affective synchrony, when much of the body's physiological state is not outwardly observable? Some instances of physiological synchrony occur because two members of a dyad are attending to the same

external event; e.g., two friends watching a scary movie together will have highly synchronous SNS activity simply because they are responding to the same stimulus. Such parallel affective experiences can still increase feelings of social closeness and liking (Cheong et al., under review). However, this form of synchrony does not require that partners be able to see, feel, or hear each other, and does not involve mutual causal influence between partners' affective states.

In instances where partners are influenced by each other's physiological states—and not a third variable in the environment—the partners must somehow transmit information about their physiological oscillations (Repp & Su, 2013). In other words, they must produce observable cues that their partners embody, and such behavioral synchrony then facilitates physiological synchrony (e.g., Oullier et al., 2008). The observable cues may be tactile (Chatel-Goldman et al., 2014; Waters et al., 2017), visual (Schmidt & O'Brien, 1997; Schmidt et al., 1990), or auditory (Eckland et al., 2019), the latter being particularly powerful synchrony attractors (Repp & Penel, 2004). The more partners attend to each other's expressive cues, the more likely they are to synchronize with them (Richardson et al., 2007), highlighting the mediating role of communication. Partners may even achieve mutual eye contact in order to increase their partner's attention to their communicative signals and thereby increase interpersonal synchrony (Leong et al., 2017).

Communication takes two forms: signals and signs (Bradbury & Vehrencamp, 2011). Signals are communicative behaviors whose primary function is to transmit information between individuals. A soothing spoken utterance intended to calm a restless baby and a scream that alerts group members about danger are two examples of communicative signals. Communicative signals have predictable effects on a perceiver's physiology, as demonstrated by Martin et al. (2018) in a study of the effects of different types of smiles on heart rate and cortisol production. People can also influence the physiology of their interaction partners by producing affect-modulating signs—behaviors that incidentally convey information about the producer's affective state. For instance, shaky hands might be a sign (rather than a signal) of anxiety that can mediate the transfer of arousal from one person to another. Some behavioral cues do not fit neatly on one side of

the sign-signal dichotomy; e.g., is tearful crying a communicative signal or a sign-like byproduct of physiological dysregulation? But for our purposes, the relevant point is that physiological affective synchrony in a dyad is mediated by the continuous exchange of perceptible signs and/or signals about the partners' internal states.

How much communication is required to maintain affective synchrony in a dyad? Dyads can be more or less similar in their affective and physiological responses to events, perhaps due to personality differences. Vallacher et al. (2005) argue that such similarity will determine how much communication and interpersonal influence the dyad needs to maintain physiological synchrony. Dissimilar dyads need consistent behavioral cues to maintain synchrony, and when communication channels are removed, they will quickly become decoupled. Highly similar dyads, on the other hand, can maintain stable synchrony for more time in the absence of communication.

Demonstrations of Expressive Synchrony

Behavioral components of emotion, described above, can trigger affective synchrony. For instance, a baby's cry of distress might cause the caregiver to match the distress in some aspects of time and space, even if the caregiver does not (usually) show behavioral synchrony in the sense of bursting into tears. But increasing evidence suggests that dyads do frequently align their bodily expressions of affect, suggesting a system of expressive and physiological synchrony. Comprehensive reviews of behavioral synchrony and the closely related phenomenon of non-verbal mimicry (i.e., similarity in form but not the timing of expressive behavior) exist elsewhere (e.g., Lakin, 2013; Repp & Su, 2013; Wheatley et al., 2012). So, we focus here on the conditions under which expressive synchrony is most likely to emerge.

Expressive synchrony is most frequently observed during positive affective interactions. For instance, Riehle et al. (2017) examined the synchrony of activation of smiling and frowning muscles with methods of electromyography (EMG) while participants discussed positive and negative life events. Compared with pseudo-dyads, true dyads synchronized their smiles, as estimated using windowed cross-lagged correlation analysis. Synchronization of smiles was rapid: after one interactant smiled, their partner smiled within 200–1000 ms.

Interactants' frowns did not appear to synchronize, suggesting that (previously unacquainted and gender-matched) interaction partners are more likely to synchronize positive compared with negative expressions.

Other evidence supports the notion that synchrony tends to accompany positive affect. Likowski et al. (2011) induced happiness or sadness in participants and then exposed them to images of facial expressions. Using EMG to measure participants' facial muscle activity, they found that happy participants were more likely than sad participants to align their faces to match both the positive and negative facial expressions. Mønster et al. (2016) found that smile synchrony within newly formed cooperative teams was correlated with positive team outcomes, while sympathetic nervous system synchrony (measured via skin conductance) was correlated with negative team outcomes. Such findings highlight that not all synchrony is desirable, an idea we return to later.

Dyads working toward a shared goal that requires coordination are also more likely to align their expressions of emotion. Louwerse et al. (2012) had participants perform a map task (Anderson et al., 1991) while they were videotaped. The task involved unscripted communication about particular routes. Knowledge of the route was distributed between the Instruction Giver, whose maps showed the route, and the Instruction Follower, who had to reproduce the route on a similar map. Maps showed, to different degrees, common landmarks, but some landmarks on the Followers' maps were obscured by grey "inkblots." Coders trained in the Facial Action Coding System (FACS; Ekman et al., 2002) classified participants' facial movements including not only (of interest here) signs of laughter and smiling but also manual gestures and features of the language. Findings revealed significant synchrony across modalities. In addition, some modalities, including laughter and smiling, showed higher synchrony when landmarks were more extensively obscured by the inkblots, making communication more difficult. The peak latency between one partner producing the behavior and the other partner matching them depended on the behavior, although most latencies were within a few seconds. This suggests that when communicative channels sync in

cooperative interactions, it provides an embodied grounding for understanding (also see Chartrand & Bargh, 1999; Golland et al., 2019).

A role for expressive synchrony in communication was demonstrated recently in our laboratory (Zhao et al., under review). Specifically, we tested the prediction that when people interact without the use of spoken language, they become more facially expressive and these expressions become more synchronized in order to compensate for the loss of communication through the verbal channel. Working in pairs, participants took turns completing trials of four different tasks in which they could earn points, awarded to the dyad as a team. Two of the tasks, a risk-taking task and a Jenga tower-building task, were designed to elicit emotion during joint action. Importantly, pairs were assigned to either a spoken language permitted or spoken language not permitted condition. As expected, in the latter condition, in which pairs could not use spoken language, both facial expressiveness and also facial expressive synchrony were higher than in the spoken language permitted condition.

In instances of expressive synchrony where there is a clearly identifiable "leader"—for instance, during unidirectional communication—one might assume that the "synchronizer" is always temporally lagging behind the "leader." However, the synchronizer's expression can predict and precede the onset of the leader's expression. In a documentation of predictive smiling, Heerey and Crossley (2013, Study 2) estimated smile onset asynchronies, or the time lag before an individual returned genuine and polite smiles. Past research has demonstrated that people sometimes return smiles reactively with time lags longer than 200 ms, which is usually conceptualized as facial communicative mimicry (e.g., Wood et al., 2016). The researchers reasoned that synchronization within 200 ms after smile onset reflects the prediction of impending facial expressions in the partner because perceptual processing and subsequent motor output take longer than 200 ms (Sanders, 1998).

Participants in the study (Heerey & Crossley, 2013) learned to associate neutral faces with key presses, and correct responses were either rewarded with genuine or polite smiles. Participants learned stimulus–response mappings more quickly when the mappings were reinforced with genuine, compared with polite, smiles. In addition, the

genuine smiles were returned predictively to a higher extent, suggesting the anticipation of social reward (e.g., a genuine smile), which has been observed in other social learning paradigms (Schultz, 2007). These findings along with those of Riehle et al. (2017), mentioned previously, provide quantitative evidence of predictive facial synchrony. They also support the earlier claim that synchrony is more common for positive signals, here manifested as genuine (as opposed to polite) smiles.

What is the relationship between expressive and physiological synchrony? We argued earlier that behavioral cues are the communicative medium through which physiological synchrony is achieved. Expressive synchrony can trigger synchrony of internal states (e.g., physiological synchrony) by continually linking partners' behavior (Feldman et al., 2011). Expressions are often an embodied manifestation of an internal physiological state and can, therefore, be an observable and transferrable mediator of physiological synchrony. In a study in which strangers watched videos together, moments of synchronous smiling (measured with facial electromyography) correlated with moments of cardiovascular synchrony (Golland et al., 2019). Expressive synchrony establishes moments of intensive interpersonal coupling and connection. Expressive synchrony, like affective synchrony more broadly, thereby enables information exchange, co-regulation, and social bonding within the dyad. We explore these adaptive consequences next.

Functions of Affective Synchrony

What is the adaptive function of synchrony? Maybe synchrony has no function and is instead always a by-product of a simpler physical process. For instance, ticking metronomes will fall into sync if they are physically coupled via a shared surface. But we would not say that the metronomes being in sync have a ***function***. Thankfully, people are more complex than metronomes. Evidence suggests that we reap a number of benefits by connecting with social partners through affective synchrony.

We propose three overlapping but specific adaptive functions of affective synchrony (see Fig. 17.1). First, affective synchrony, like other

forms of interpersonal synchrony, reduces the number of uncorrelated variables (i.e., complexity) of a dyad, making information processing easier for both partners. In other words, shared affective responses reduce the number of time-varying affective response variables within the dyad from two to one. Second, by sharing their emotional states with others, people are able to detect and respond to challenges and opportunities in the environment more efficiently. The benefits of this ability can be measured on multiple timescales: at the moment, spouses can pool their resources to co-regulate each other's distress. Caregivers can instill immediate fear and freeze in a baby about to walk off a step by vocalizing their alarm. Over the long-term, affective synchrony enables social learning, as partners align with each other's responses to classes of stimuli that are encountered on repeated occasions. Finally, extensive evidence suggests affective synchrony enhances feelings of similarity and closeness and strengthens social bonds. We explore these three functions next.

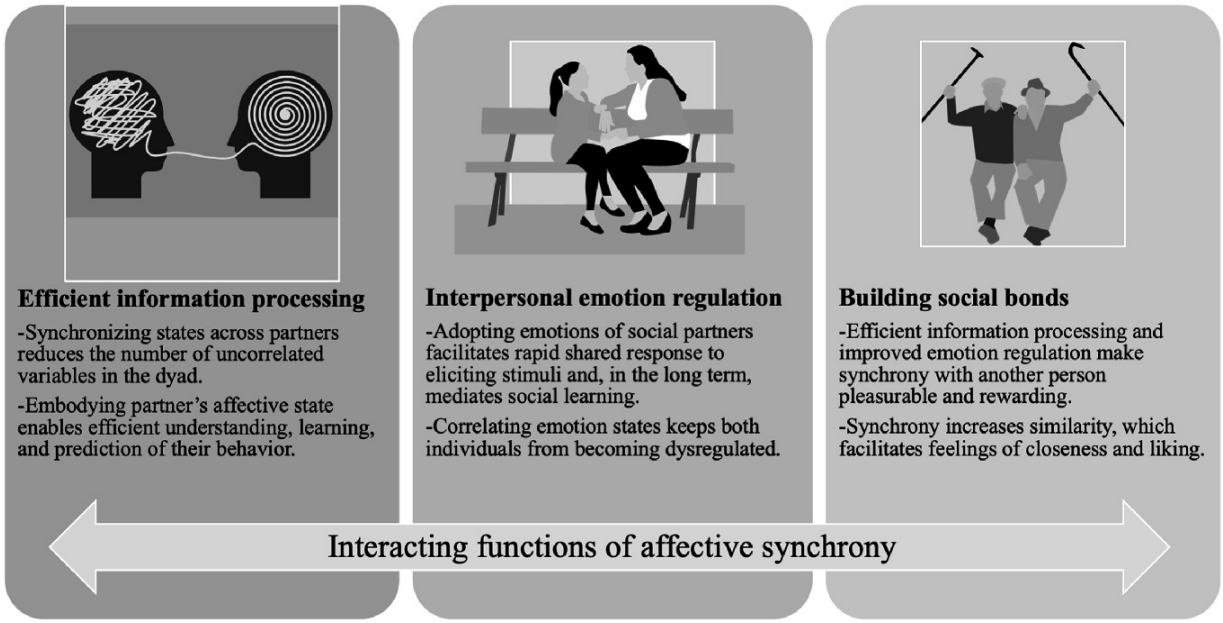


Fig. 17.1 We propose three interconnected levels at which affective synchrony is adaptive

Efficient Information Processing

We theorize that affective synchrony enables more efficient information processing. Koban et al. (2019) posit that, as a general rule, interpersonal motor synchronization arises as a result of the tendencies of the brain to conserve resources and optimize its

representation of the environment. When interacting with a partner, people must represent both their own behavior and internal state and their partner's behavior and internal state. From the outset, the behaviors and internal states of social partners are likely to be similar: People usually choose to affiliate with similar others (e.g., Bahns et al., 2017), and close relational partners tend to share goals, often working together on tasks that require coordination. If members of an interacting dyad increasingly embody each other's emotional states and behaviors over time, they can jointly represent their own state and actions with the state and actions of their partner. Coupling these self and other representations gives each partner one less thing to keep track of, so interacting synchronously reduces cognitive effort.

Though Koban et al. (2019) focus on spontaneous motor synchronization, the same principles apply to affective synchrony. People use embodied sensorimotor simulation to understand other people's internal states and motivations in addition to their motor actions (Gallese & Goldman, 1998; Wood et al., 2016). Accordingly, coupling one's own emotional state with the representation of a partner's emotional state is an efficient way to understand the partner's emotions, just as motor synchronization is an efficient way to understand the partner's actions and intentions. Because the partners' emotions are aligned, an individual's own emotional state can be used to predict the future behavior of their partner (Friston & Frith, 2015; Heerey & Crossley, 2013; Seth & Critchley, 2013). For instance, afferent feedback to one's brain from one's smile represents a prediction about a partner's next facial expression and likely social intentions. Affective synchrony, in this case, supports interpersonal coordination. By increasing the ease and efficiency of social interactions, synchronization facilitates information processing and enhances communication between interacting partners.

Interpersonal Emotion Regulation

As humans, we share almost everything. We share living spaces and communities with people who often share our goals. We feed each other and regulate our temperatures by being close to each other. We share our microbiomes, circadian rhythms, beds, ideas, language, recipes, laundry, beliefs about cosmology, political preferences, and diseases. According to Social Baseline Theory, the human brain

assumes that people have access to social relationships with interdependent others who share our goals and resources (Coan & Sbarra, 2015). To survive as a species, we have always needed to live and share internal states, possessions, environments, and outcomes with other humans.

Sharing begins in an extreme form: when we are infants, we are helpless and entirely reliant on our caregivers. Human infants cannot regulate their physiology on their own. They depend on caregivers to regulate their diet, temperature, and other aspects of their autonomic function. The infant first experiences physiological and behavioral codependence—and synchrony—with another human while still inside the womb. Physiological and behavioral synchrony between the infant and caregiver continues after birth, as the caregiver is closely attuned to the rhythms and needs of the infant. For instance, parents time their active caregiving to coincide with newborn's sporadic periods of alertness (Feldman, 2012).

Over the course of development, the growing infant learns to associate their behavioral and physiological states with the corresponding states in their caretaker. The infant then learns to reverse the causal relationship in order to synchronize with the caregiver to regulate itself and influence the caregiver (Atzil et al., 2018). The tight coupling of physiological and behavioral processes present in an adaptive infant–caregiver relationship sets the stage for a lifetime of interpersonal synchrony and co-regulation (this developmental trajectory for synchrony has also been observed in dolphins: Fellner et al., 2006).

Affective synchrony allows us to regulate the behavior of others, particularly when they are unable to regulate themselves (Saxbe et al., 2020). Affective synchrony allows partners to foster context-appropriate emotional states, such as achieving a state of calm prior to falling asleep. According to Social Baseline Theory, a function of the co-regulation of emotion is to render more metabolically efficient the cost of coping with the opportunities and challenges of social life (Beckes & Coan, 2011; Coan, 2008; Coan et al., 2006). Adaptive co-regulation does not always mean up-regulating positive states or down-regulating negative states. Sharing negative effect is adaptive in certain contexts; as we have seen, the sharing of stress from the mother transmits an

understanding of the presence of threat in the environment to their infant (Waters et al., 2014).

Correlational evidence indirectly supports the notion that affective synchrony enables co-regulation of emotion. The degree to which mother–infant dyads achieve behavioral synchrony is positively correlated with the infant's cardiac vagal tone (Porter, 2003). It may not always be the case that the person ***being*** regulated is the follower. The regulating person, such as a caregiver, may first match their partner's distress, for instance becoming stressed upon hearing the infant's cry, and then bring the dyad as a single unit back to a low arousal set point.

The concept of co-regulation of affect is central to Butler's (2011) Temporal Interpersonal Emotion System (TIES) model, which proposes that in the context of social interactions, emotions can be thought of as self-organizing dynamical systems in which the components of emotions emerge and interact across interactants. In the model, co-regulation is operationalized as the bidirectional linkage of oscillating emotional channels between partners, which contributes to emotional stability for both partners (Butler & Randall, 2013). In a healthy close dyad, the oscillating activity levels in each person's physiological systems are tied to their partner's. If one person's physiological rhythm becomes dysregulated—for instance, decoupled from relevant external cues (as in the case of chronic anxiety)—their partner's well-calibrated physiological state can regulate them and bring them back to a more adaptive physiological state. For the examples of adult dyads described earlier, including romantic couples and therapeutic alliances, physiological synchrony plays a developmentally appropriate function of contributing to the co-regulation of emotional responses (Liu et al., 2013; Papp et al., 2013; Saxbe & Repetti, 2010).

In a functioning dyad, partners adjust synchrony according to their own needs and resource availability. The amount of affective synchrony a caregiver–infant dyad achieves is a function of how much co-regulatory support the infant needs and how much co-regulatory support the caregiver is able to provide. A recent study examined the relationship between infant–mother behavioral synchrony and parasympathetic nervous system (PNS) and SNS activity during the

mildly stressful still face paradigm (Busuito et al., 2019). Babies with lower PNS activity—infants who might need greater co-regulatory support—elicited more synchronous behavior from their mothers. Mothers who engaged in more synchrony, on the other hand, had ***higher*** PNS activity. The authors concluded that these less-aroused mothers were more able to attune to and regulate their babies' distress, perhaps because they had greater emotional resources available to them.

Affective synchrony does more than allow partners to influence each other's in-the-moment affective states. It also helps them teach each other adaptive patterns of emotional responding, which we might consider a long-term manifestation of co-regulation. Social animals use the experiences of others as a source of information about the local environment—for example, which foods are safe to eat and which animals are dangerous (Barrett & Broesch, 2012). If a group of people are in the same environment and have similar goals, it would be inefficient for each one to appraise the environment and its threats and opportunities separately. By yoking their expressions and physiology, they share emotions, which guide and motivate coordinated responses to threats and opportunities. The capacity to synchronize affective responses with others promotes efficient and adaptive responding to stimuli, perhaps before one has even had a chance to appraise them, which is one of the metabolic hallmarks of social learning (Gilbert et al., 2009).

A number of non-human animal groups exhibit the beneficial effects of sharing behavioral responses conferred by embodying each other's expressions and experiences of emotion in the form of affective synchrony. Animals living in groups across phylogeny produce alarm calls when they detect a threat, efficiently spreading their heightened arousal and vigilance to the rest of the group (Snowdon, 2003). The efficiency of this strategy depends on the rest of the group immediately embodying the affective state of the alarm caller—if all group members had to independently detect the threat before acting, it might be too late. Affective states are indeed contagious across animals regardless of whether all group members actually detected the relevant stimulus. For instance, when a stressed zebrafish is placed in a tank with a second non-stressed zebrafish, the fish "average out" their affective

states and both become moderately stressed (Crane et al., 2018). The fish pool information about the environment by synchronizing their affective states through observable cues may be visual, olfactory, or otherwise.

Humans similarly share their affective states and the accompanying behavioral responses to evocative stimuli. For instance, as described above, Waters et al. (2014) reunited infants with their mothers after the mothers were exposed to a stressful situation. Infants aligned their states to the heightened arousal state of their mothers, even though they were not directly exposed to the stressor. This affective synchrony was achieved largely through touch (Waters et al., 2017). The adaptive benefits of such affective co-regulation are clear. By sharing her affective response with the infant, the mother is guiding the infant's behavior (see also Vaish & Striano, 2004). Indeed, the researchers found that the babies behaviorally avoided the person who caused the stress in their mother, even though that person had not done anything to threaten them directly (Waters et al., 2014). The child also learns how to respond to similar stimuli in the future (Skinner et al., 2019). As these examples illustrate, affective synchrony is a general mechanism for social learning (Klinnert et al., 1983).

Building Social Bonds

As we have shown, synchronizing with a partner is efficient. Merging one's representation of one's own state and actions with one's representation of a partner's state and actions reduces cognitive effort, so partners can process the unfolding interaction with greater ease. In general, processing fluency feels good and leads to positive evaluations (Reber et al., 1998). Because synchronous interactions afford savings in effort and energy consumption, they feel easy and rewarding. People feel good when they are "in sync" with an interaction partner.

Perhaps due to the pleasant feelings that accompany being in sync, synchrony is also linked to positive social outcomes. Behavioral and vocal synchrony increase prosocial behavior, perceived social bonding, and positive affect (Mogan et al., 2017). Moving synchronously with social partners leads people to perceive themselves as more similar and increases feelings of compassion and willingness to help (Valdesolo & DeSteno, 2011). Being in sync also induces feelings of

closeness and connection (Sharon-David et al., 2018), even in groups (e.g., Jackson et al., 2018; Launay et al., 2016).

Of course, many empirical demonstrations linking synchrony to prosociality and rapport rely on brief manipulations in which experimental dyads are led to produce synchronous motor behavior such as tapping, clapping, or rocking. We expect that aligning the form and timing of emotional expression and physiology with relational partners in the real world feels at least as intimate as tapping a beat in time with a stranger in a lab experiment. Indeed, Páez et al. (2015) found that people who reported having felt in synchrony with others in naturalistic settings, including a joyful folkloric march and a negatively charged political demonstration, felt greater social support and stronger emotional involvement. Such findings suggest that sharing emotions in real time with another person signals that one's interaction partner is similar to us and likely shares our goals; after all, both are appraising (and preparing to act on) the environment in the same way.

Affective synchrony may also be rewarding because influencing each other's emotional states is pleasurable in itself. When a person smiles and they receive a smile in return, they experience emotional self-agency, or the feeling of having caused the partner's emotions. The process establishes a general feeling of a causal connection and reciprocal influence through cycles of non-verbal communication (e.g., Feldman, 2011). Heightened emotional self-agency has important benefits (Feldman et al., 1999). The benefits can be temporary: when individuals experience themselves as the cause of another's joy, they will likely continue to perform similar behaviors. The consequences are also long term: individuals with a general sense of emotional self-agency have higher social and emotional outcomes overall.

In sum, behavioral and affective alignments are pleasurable and cause partners to feel close, motivating them to continue to interact over time. The feelings of ease, self-agency, and rapport experienced during synchronous interactions reward the interacting partners, strengthening the bonds between them.

Costs of Affective Synchrony

Co-regulation, ease of information processing, and building of social bonds are the proposed functions of affective synchrony. But

even functional behaviors can be dysfunctional if they are insensitive to context. Constant, perfect synchrony is maladaptive (Mayo & Gordon, 2020). After all, if partners perfectly matched each other, they would be unable to benefit from having two brains and bodies rather than one. Moments in which synchrony is beneficial are complemented by moments in which independent behavior is beneficial (Koban et al., 2019; Sebanz et al., 2006; Skewes et al., 2015). Indeed, synchrony tends to occur less than half of the time in a functioning dyad (Feniger-Schaal et al., 2016; Noy et al., 2011).

Mayo and Gordon (2020) refer to dyadic synchrony as a "meta-stable" phenomenon, meaning the dyad does not stably maintain a constant synchronous state, but rather the flexible ability to alternate between synchronous and independent behavior. We have already seen evidence that dyads calibrate their affective synchrony to fit the demands of the interaction (Zhao et al., under review). Danyluck and Page-Gould (2019) demonstrated that PNS and SNS synchrony depend on whether dyads are engaged in a cooperative or competitive context as well as the extent to which they are allowed to interact (see also Miles et al., 2010; Paxton & Dale, 2013).

Affective synchrony within a dyad can be maladaptive when the shared state is negative, and the partners amplify and escalate their unpleasant emotion. In dyads that effectively co-regulate each other, the negative emotion of one person is counterbalanced by their partner, returning the dyad to their set point (Reed et al., 2015). Parents, for instance, tend to decrease their physiological arousal when the infant's arousal is heightened (Wass et al., 2019). But in dyads that are dysregulated, the negative emotion of one partner is reinforced by the other's, creating a positive feedback loop of heightened distress.

Growing evidence supports the insight that synchrony during negative affective states is often maladaptive (Saxbe et al., 2020). Romantic partners discussing loss and bereavement showed a negative correlation between heart rate synchrony (indicating shared negative arousal) and feelings of compassion (Corner et al., 2019). In other words, being a supportive partner during a distressing conversation entails ***not*** synchronizing with the other person's physiology. Vocal pitch synchrony in client–therapist dyads is associated with worse therapeutic relationships and greater client

distress (Reich et al., 2014). In the therapeutic relationship, then, synchrony to achieve and convey empathy must be tempered, lest the therapist amplifies the client's distress by reflecting it back to them. Anxiety about the ongoing interaction can also be transmitted from one partner to the other: in a cross-race interaction, a White partner's interracial anxiety can make their Black partner more anxious (West et al., 2017).

While the tendency to match the positive emotions of others is associated with well-being and sympathetic caring, the tendency to match the negative affective states of others is associated with emotional distress and personality disorder symptomatology (Murphy et al., 2018). Mothers with depression synchronize more with their babies during negative states than do mothers without depression (Field et al., 1990). Rather than co-regulating the baby and helping it learn how to handle its distress, this dysregulated form of synchrony may heighten and reinforce the baby's distress.

Suveg et al. (2016) measured the heart rate synchrony of mothers and their 3-year-old children during an interactive Etch-a-Sketch task and a control period (in which the pair sat quietly). Physiological synchrony was present during the interactive task and such synchrony predicted the child's ability to self-regulate. Of note, this effect was not observed for a subsample of families that were at high risk, suggesting that the achievement of synchrony can be disruptive to other processes if physiological responses to social contexts are inappropriate or dysregulated.

We posit that context-insensitive affective synchrony is further maladaptive because it disrupts individuals' emotional functioning. The more partners' affective states influence each other, the less they will be influenced by factors outside the dyad. The dyad will, therefore, be necessarily less emotionally responsive to salient events in the environment. Adaptive emotional responding is flexible and tuned to external events (Schuyler et al., 2014). Preliminary evidence suggests interpersonal synchrony may in fact impede self-regulation (Galbusera et al., 2019). Synchrony can also strengthen in-group bonds to the detriment of intergroup relations, providing further evidence that the benefits are context-dependent (Tamborini et al., 2018).

Besides falling into emotion dysregulation, a dyad that is inflexibly synchronized may suffer information processing disadvantages (in contrast to the information processing advantages of synchrony discussed in an earlier section). Social groups afford informational advantages to group members, as the members can crowdsource perception, prior knowledge, and decision-making (Bietti & Sutton, 2015). But part of those advantages come from the information processing diversity of the group (e.g., Derex & Boyd, 2016), including diversity in their emotional responding. If social partners react identically to all events because they are synchronized, they lose some of that advantageous diversity. Behavioral synchrony in a dyadic problem-solving task was negatively associated with overall performance (Abney et al., 2015). We suggest extreme affective synchrony, beyond mere behavioral synchrony, might have similar drawbacks. In line with this reasoning, Mønster et al. (2016) found that physiological synchrony among cooperating team members was positively related to team cohesion but negatively related to a team's likelihood of adopting a new (potentially more optimal) task behavior over multiple sessions. The teams that synchronized excessively, rather than flexibly switching between synchrony and independence, did not benefit from having multiple minds working to solve a problem.

To summarize, affective synchrony is not always a good thing. When dyads synchronize regardless of context, including during negative affective states, they lose some of the co-regulatory and information processing benefits of being social.

Paths for Future Research

In the present chapter, we have integrated a large body of research that explores a particular form of embodying emotions. Rather than momentary embodiments of emotion, such as an act of facial mimicry, the concept of synchronous emotions entails the matching of expressive cues to emotion and the corresponding matching of physiological activity over real time. We have called "synchronous" those conditions in which the matching of components of emotion represents several mathematical functions including those of covariation and correlation as well as more formal oscillation.

However, this matching concept has been named by many different terms in the literature including alignment, entrainment, mimicry, mirroring, imitation and, of course, synchrony.

Future theorizing, modeling, and research will need to formalize the different manners of interpersonal matching of emotions over time. There are almost as many ways to quantify synchrony as there are definitions of the term (e.g., Butler, 2011; Moulder et al., 2018; Thorson et al., 2018). Each has its own assumptions and aims to model slightly different things. A systematic set of quantitative recommendations and an account of their uses and meanings are now sorely needed for progress in further understanding the forms and functions of affective synchrony.

A deeper understanding of the costs and benefits of affective synchrony will require an additional type of modeling, which is the modeling of synchrony itself over time. For example, while we have noted that some costs of affective synchrony are observed during states of negative emotion, it could be that synchrony is initially beneficial in supporting the understanding of even another person's negative emotions, but that a divergence from synchrony—a decoupling—is then beneficial because it aids in dyadic emotion co-regulation and the use of contextual information. That is, there may be an important difference between initial synchrony and synchrony that is "stuck" in a negative cycle or state of escalation.

Finally, the precise relationships between the synchronization of different components of emotion, including expressive cues, peripheral physiology, and neural states await further study.

Conclusion

The forms and functions of interpersonal synchrony are a rapidly expanding topic of psychological research, thanks to ever-improving measurement and analysis methods (Moulder et al., 2018; Zhao et al., under review). Affective synchrony shares many properties attributed to interpersonal synchrony more generally, such as its potential to reduce interpersonal degrees of freedom (Koban et al., 2019). But affective synchrony also exhibits some unique properties compared with pure motor synchrony. It allows dyads to co-regulate each other,

learn appropriate emotional responses, engage in empathy-related simulation processes, and strengthen their bonds. As with other forms of interpersonal synchrony, affective synchrony is most adaptive when dyads flexibly synchronize at relevant moments in an interaction (Mayo & Gordon, 2020).

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_18

18. Joint Action Enhances Subsequent Social Learning by Strengthening a Mirror Mechanism

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Abstract
Many of our activities involve joint action. Here we explore a possible consequence of joint action: Completing a task may improve one's ability to learn a novel task from a partner. In the Joint condition of three experiments, participants and experimenters jointly used a wire to cut candles for five minutes. In the control condition, the participants used the wire to cut the candles alone. After cutting, the experimenter demonstrated a novel, complex movement that was imitated by the participant. Compared to the control condition, participants in the Joint condition imitated the experimenter more accurately, at a shorter lag, and reproduced the sequence more accurately without the experimenter's involvement. In experiments using electroencephalography, we used mu-desynchronization to track changes in the action mirror neuron system produced by candle-cutting. Although we did not confirm all predictions of a mirror neuron account, the results were generally consistent with our hypothesis that joint action enhances subsequent social learning by changing a mirror

mechanism. In addition, the Joint participants reported greater closeness to the experimenter. We end the chapter by brie ly exploring the consequences of joint modi cation of the mirror neuron system for social relations, teaching, and rehabilitation.

Keywords Embodied cognition – Joint action – Social learning – Mirror mechanism – Motor system

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In this chapter, we describe experiments that closely relate the bodily and social nature of human beings: When we act together, we develop a joint body schema. That is, we mold our action abilities to those of our partners (Soliman et al., 2015). As a prosaic example, consider dancing with a partner. Step length, forces, directions, and choice of dance movements are all molded to those of the partner. Here we address two particular questions about this type of social learning. First, does having a joint body schema enhance our ability to learn from our partner (can we learn a new dance step better from our old partner compared to a new partner)? Second, do these behavioral changes result from changes in the mirror neuron system? Implications of these ndings for close social relations, teaching, and rehabilitation are brie ly explored in the Discussion section.

The Social Nature of Intelligence and Mirror Neurons

Michael Tomasello has been a leader in the development and demonstration of the social nature of intelligence. According to his cultural intelligence hypothesis (Tomasello, 1999), human intelligence exceeds that of other great apes because we evolved the ability, need, and desire to pay attention to one another. One implication of this hypothesis is that natural human abilities, that is, those that are not based on formal education, should exceed those of other great apes in the social domain, but not necessarily in the physical domain. Herman et al., (2007; see also Bohn et al., 2020) tested this implication by comparing the abilities of 2.5-year-old children to chimpanzees and orangutans in two types of problem-solving tasks. The physical domain

tasks included problems dependent on space, quantities, and causality. There were no differences between the children and the other great apes in these domains. The social domain tasks included problems dependent on social learning, communication, and theory of mind. In these tasks, the abilities of the human children greatly exceeded those of the chimpanzees and orangutans. In fact, in other work, Tomasello has demonstrated that children, but not chimps, prefer to cooperate in problem solving (Rekers et al., 2011).

A possible neurophysiological mechanism behind the social nature of human intelligence is the mirror neuron system. Mirror neurons (for a review see Rizzolatti & Sinigaglia, 2016) were first discovered in the macaque premotor cortex. These neurons are active both when the animal is engaged in a particular action (e.g., grabbing a peanut) and when that animal observes the experimenter performs the same action. A number of researchers (e.g., Gallese, 2005; Rizzolatti & Sinigaglia, 2016; Uddin et al., 2007) suggest that mirror neurons are the mechanism by which A can better predict B's actions and understand B. That is, because A's mirror neurons fire when B acts, A can understand B in terms of A's own ability to act and in terms of A's own intentions when taking that action. Mirror neuron systems have also been linked to empathy in that they have also been located in emotional centers of the brain (e.g., Gallese et al., 2004). In fact, in humans, mirror neurons have been found in multiple areas of the brain related to action, emotion, and memory (Mukamel et al., 2010).

Mirror neurons and Tomasello's cultural intelligence hypothesis are complementary. That is, living in large groups provided the selection pressure to evolve an extensive mirror neuron system to better engage with others. That, in turn, allowed for a greater understanding of the actions and intentions of others in the group and a concomitant growth of the culture.

Joint Action

Within the field of cognitive psychology, there have been several approaches to studying mechanisms of social interaction and intelligence. By far, the area that has received the most attention is language, which is perhaps the most social of all human skills: The

whole point of language is communication with another. Ironically, most of the work on language within cognitive psychology has treated it as an individual skill rather than a social skill (for some prominent exceptions, see Clark, 1996, and Pickering & Garrod, 2004). Like other forms of joint action, language is probably dependent on mirror neurons (Glenberg & Gallese, 2012; Rizzolatti & Arbib, 1998).

Another approach to studying social interaction and cognition is joint action, that is, the types of cooperation and coordination that emerge when two people engage in completing a joint task. The study of joint action has produced such a significant body of literature that Pesquita et al. (2018) note in their review that joint action deserves to be regarded as a "field" of research.

Here, we contribute to this field of research by describing a previously unreported effect: Following joint action, there is a lasting effect on social learning. That is, after persons A and B engage in joint action, A is better able to learn a new motor task from B. We argue that this effect may arise from the adaptation of a mirror neuron system and that it may be important for close social interactions, teaching, and rehabilitation.

Although the field of joint action consists of many empirical and theoretical advances (see, for example, Pesquita et al., 2018), there has been comparatively little exploration of ***future*** consequences of joint action. That is, once the joint action experience has ended, are there any lasting effects? Wiltermuth and Heath (2009) examined synchronous mimicry and demonstrated a subsequent increase in cooperative behavior. Similarly, Tarr et al. (2016) found that synchronous mimicry leads to increases in social bonding or liking. However, we are unaware of any research documenting what may be an equally important consequence of joint action: facilitation of subsequent social learning. In the current research, social learning is operationalized as the learning of a new motor skill through direct observation of another. In the Discussion section, we speculate on how our results could apply to the learning of other cognitive skills.

The potential for joint action to facilitate social learning is implicit in the association of joint action and mirror neurons. As noted above, by virtue of joint action, A becomes a better predictor of B's behavior. Given this increase in prediction accuracy, it is a short step to the

facilitation of social learning. That is, A should be better able to follow B's actions in a related, but new task, and A should be better able to map B's actions onto A's own motor system. Neuropsychological studies of imitation point to the importance of this sort of mapping. For example, Chaminade et al. (2005) show that imitation requires parsing B's motor segments and body-part conﬁgurations in terms of A's own body representation. Thus, enhancing the mapping from B to A through previous joint action should enhance the accuracy of imitation and social learning. And, as suggested by Gallese (2005) and Uddin et al. (2007), mirror neuron systems appear to provide at least part of the neurophysiological substrate that allows this parsing of motor segments and mapping to the self.

We now have most of the components needed to situate the present investigation. Joint action modiﬁes the representations of both the self and the other, potentially through changes in mirror neurons. These modiﬁcations should facilitate the ability to parse and map another's actions onto one's own action system and thereby enhance social learning. In our ﬁrst experiment, we demonstrate that following joint action there is enhanced social learning of a new motor skill. Then, in two experiments using electroencephalography (EEG), we provide preliminary evidence that this social learning results from adaptation of the mirror neuron system. The data from the three experiments that we report below have not been published elsewhere.[1]

The ﬁnal component needed to situate the research is a description of the joint action task that we used (see Fig. 18.1). This task was introduced by Soliman et al. (2015). Dyads engage in jointly moving a wire to cut through candles. This task requires interpersonal spatial and temporal synchrony in control of forces. The task also results in two aftereffects. First, after jointly cutting candles with the experimenter, the participant confuses stimuli near the experimenter's body with stimuli near her own body. This confusion is demonstrated when the participant is asked to discriminate whether she feels a vibratory stimulus on her thumb or index ﬁnger. The accuracy of this discrimination is reduced when the participant sees a visual stimulus near the experimenter's incongruent (i.e., index ﬁnger or thumb) digit. Second, after joint cutting with the experimenter, the participant's ability to draw straight lines is affected by watching the experimenter

draw circles. Soliman et al. (2015) call these aftereffects a joint body schema (JBS).



Fig. 18.1 The participant (right) and experimenter (left) in Phase 1 of the Joint condition

Thus, previous research has demonstrated decrements in performance following joint action when attempting to ***ignore*** the actions of a partner. Here, we examine whether attempts to ***learn*** the actions of a partner are more successful following joint action. Furthermore, we use electroencephalography (EEG) to examine whether the observed aftereffects appear to be the outputs of changes to the mirror neuron system. Finally, in study 3, we examine whether joint action increases closeness to the partner with whom one has coordinated.

Does Joint Action Facilitate Later Social Learning?

In our first experiment, we test the prediction that the JBS aftereffects may be harnessed to improve novel motor pattern imitation and learning. We begin with an overview of our methods and predictions followed by a more detailed summary.

Following a brief practice session described below, in Phase 1 of the experiment, participants in the Joint condition cut candles with the experimenter for five minutes to induce the JBS aftereffects (exactly as in Soliman et al., 2015; see Fig. 18.1). The participants in the Solo condition used a wire with a weight on one end (to keep the wire taut) to cut candles alone while being watched by the experimenter. In Phase 2, the experimenter became a trainer and used a pen-shaped computer mouse to demonstrate a novel, variable-speed sequence of left-hand movements along the sagittal plane (toward and away from the body; see Figs. 18.2 and 18.3). The participant used a similar mouse with the left hand to imitate the trainer and learn the sequence. In each of the three blocks, the trainer demonstrated the sequence three times while the participant simultaneously imitated the movements. On the last trial of each block, the participant had one opportunity to freely reproduce the sequence without the trainer. The predictions are that participants in the Joint condition (compared to those in the Solo condition) will show (a) better imitation (on the first three trials of a block), (b) imitation at a shorter lag, and (c) higher accuracy on the last (free production) trial of each block. There was also a transverse (left to right) component to the task (described below). This transverse component allowed us to determine if enhanced learning specifically results from enhanced motor imitation rather than, for example, a desire to please the experimenter (cf, Tarr et al., 2016).



Fig. 18.2 The participant (top) and trainer (bottom) in Phase 2. Note that the trainer's monitor is tilted so that the sagittal pattern, conveyed by a moving dot, cannot be viewed by the participant

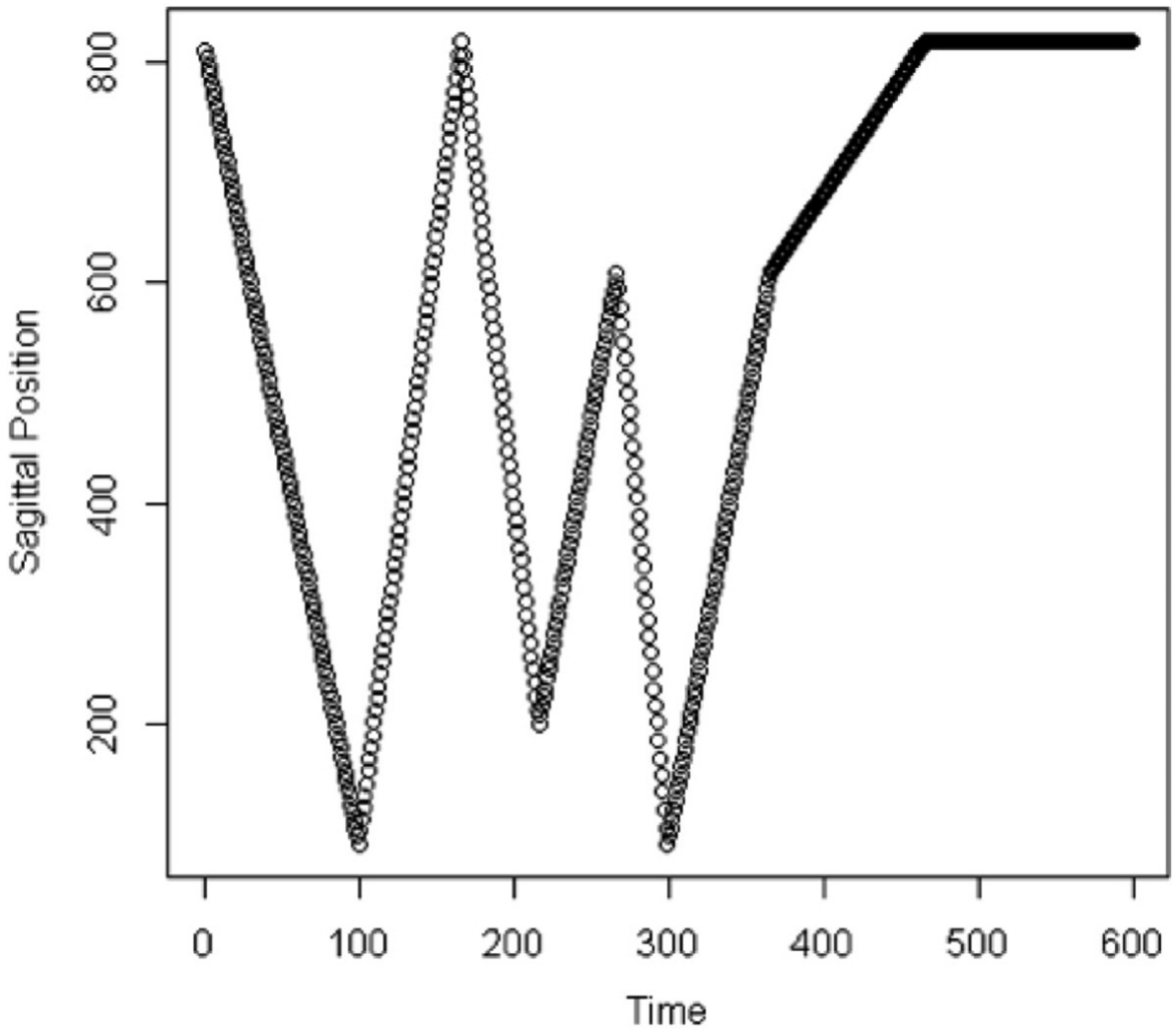


Fig. 18.3 A time-series representation of the ideal trajectory of hand flexion–extension of a participant's left hand during imitation. Time (in 7 ms increments) is on the x-axis, and position (in pixels) along the sagittal plane is on the y-axis

The participants were 50 undergraduate students at Arizona State University. However, data from three participants were excluded because they had inadvertently turned off the pen mouse (see below) so that no data were collected in Phase 2. Thus, the data reported here are from 47 right-handed participants who were randomly assigned to either the Joint (n = 23) or the Solo (n = 24) sawing groups.

Before Phase 1 candle cutting, all participants practiced a simple version (three trials of a simplified pattern) of the motor imitation task used in Phase 2. This practice served several purposes. First, it introduced the participants to the apparatus (e.g., the pen mouse) and the general procedure. Thus, after candle-cutting in Phase 1, the

participant could proceed directly to the motor learning task when the JBS is expected to be at its maximal strength. Second, data from these practice trials will be used to show equivalent imitation ability before the introduction of the candle-cutting task. In fact, participants in both conditions improved over the three trials by increasing the accuracy of following the trainer's movements and shortening the average lag between their movement and the trainer's movement. Importantly, however, there were no statistically signi cant differences between the groups before the introduction of the candle-cutting task. That is, the groups were equivalent in ability to imitate the trainer before candle-cutting.

In Phase 1 (after the three practice trials), the Joint participant used the right hand, and the trainer the left hand, to pull a exible wire sideways to cut candles down to the wick (Fig. 18.1). Candles were replaced as needed and cutting continued for ve minutes. As described above, Soliman et al. (2015) provided behavioral evidence that this joint task induces a change to the body schema of the learner's idle left hand (i.e., the hand used by the partner but not the learner). The Solo control participants performed a solo version of the candle sawing task. They used their right hands to pull the wire which had a weight attached to the other end. Solo participants were watched by the experimenter during the ve-minute candle-cutting task.

After ve minutes of candle-cutting, each participant attempted to identify the location of vibratory stimuli on the left index nger or thumb while watching LEDs that ashed concurrently (for details, see Soliman et al., 2015, Experiment 1). Unfortunately, a coding error rendered these data unusable.

In Phase 2, all participants practiced a left-hand motor sequence involving holding and moving a pen-shaped wireless computer mouse inside a wooden box (see Fig. 18.2). The box (5 × 15 cm) was mounted on a tabletop approximately 30 cm from the participant with the longer axis along the participant's sagittal plane and aligned to the left shoulder. In both the Joint and Solo conditions, the trainer sat approximately 100 cm to the left of the participant and used a similar pen and box to model the sequence. The trainer was operating the pen to move a cursor on a computer screen so that the cursor tracked a pre-programmed moving dot on the screen. The screen was occluded

from the participant's sight so that the participant could only learn the movements by following the trainer's hand.

The sequence comprised two concurrent force components. The sagittal component involved moving the mouse away and toward the body through continuous arm flexion–extension strokes. Each of the strokes had a different length (i.e., variable inter-stroke reversal points) and a different speed (see Fig. 18.3 for a graphical depiction of the sequence of strokes). All strokes were performed within the middle 10 cm of the interior sagittal axis of the box.

The second motor component involved adapting to a transverse (horizontal) force field created by using two magnets. One magnet was mounted at the bottom medial side of the mouse and the other was embedded within the medial wall of the box. Participants were informed of the magnet locations. They received instructions to avoid hitting either wall of the box while performing the continuous sagittal strokes.

Critically, the trainer's apparatus contained no magnets, so her left-hand movements did not model the transverse (horizontal) component of the motor sequence. That is, she only modeled the sagittal force components seen in Fig. 18.3. The participants were instructed to watch the left-hand movement of the trainer and to imitate those movements with their own left hands while avoiding hitting the walls of their box.

Consider how having both a modeled sagittal component and a non-modeled transverse component allows us to discriminate between multiple hypotheses. Suppose that joint action simply results in greater liking of the experimenter or a greater desire to please (cf. Tarr et al., 2016; Wiltermuth & Heath, 2009). In this case, participants in the Joint condition should learn both the sagittal and transverse components more easily than participants in the Solo condition. Now, suppose instead that Joint action results in an adaptation in which the participant's motor mirror neurons are tuned to that of the experimenter/trainer. In this case, Joint participants should learn the sagittal component more easily than the Solo participants because the Joint participants are more attuned to the movements of the trainer. However, there should be no difference between the Joint and Solo participants in their ability to learn the transverse component because

that component is not modeled by the trainer (because the trainer's apparatus has no magnets).

The Phase 2 motor learning task comprised three blocks of three imitation trials, with a free production trial following the three imitation trials in each block (a total of 12 trials). During each of the imitation trials, the y- (i.e., sagittal) and x-(horizontal) coordinates of the trainer's and participant's mouses were sampled at 128 Hz. The y-coordinates were subjected to lag cross-correlation (LCC) analyses to determine the spatial similarity and temporal synchrony of the sagittal trajectories of the participant's left hand with the experimenter's left hand. That is, the participant's y-coordinate at each time point was correlated with the trainer's y-coordinate to obtain the lag 0 correlation. We then lagged the matching of the y-coordinates so that the participant's first y-coordinate was matched with the trainer's second y-coordinate, the participant's second y-coordinate was matched to the trainer's third coordinate, and so on to obtain the lag 1 correlation. We continued this process to obtain all possible lagged correlations. The maximal LCC measures the degree to which the participant is mimicking the trainer's pattern. The lag at the maximal LCC represents how closely in time the participant is following the trainer.

Performance on the three blocks of imitation trials is shown on the left-hand side of Fig. 18.4 and in Fig. 18.5. Over the course of the three imitation trial blocks, both the Solo and Joint participants demonstrated clear indications of learning. That is, for both groups, the ability to synchronize the flexion–extension component of their left hand with the sequence modeled by the trainer progressively improved from the first through the third block. Importantly, there was an advantage for the Joint participant group that presumably developed a JBS with the trainer in Phase 1. This advantage was clear during the first block, and the advantage was maintained through the third block (i.e., there was no Sawing x Block interaction). One might wonder if the Joint condition advantage observed in the first block indicates that the participants in the Joint condition were simply better imitators from the outset. Two facts speak against this idea. First, recall that the Joint and Solo participants were equivalent in their ability to imitate during the practice session before Phase 1. Second,

performance in the first block in Phase 2 was an average over three imitation trials. That is, participants in the Joint condition had ample opportunity to learn from the trainer across the three trials comprising block 1.

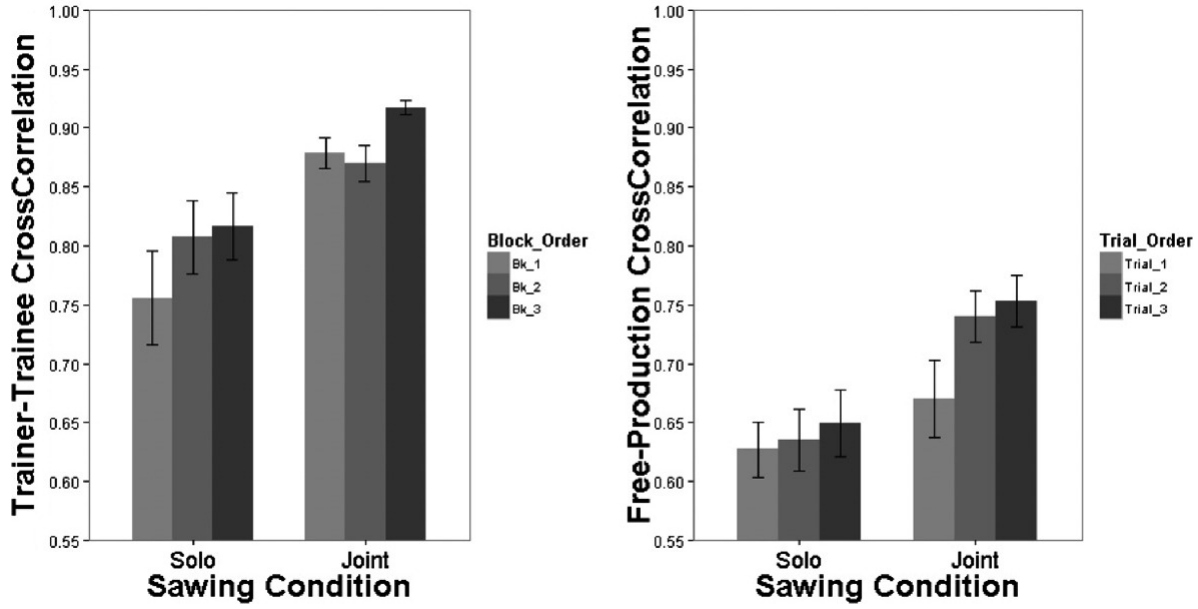


Fig. 18.4 The JBS effect on imitation and learning. Left: Maximum LCCs of the participant's and trainer's hand movement in the sagittal plane averaged over the three imitation trials in each block. The maximum correlation was obtained by successively lagging the participant's sagittal data points (compared to the trainer's sagittal data points) and choosing the maximum correlation. Error bars represent one standard error of the mean. Right: Maximum LCCs in the sagittal plane of the participant's hand movement during free production and the average trajectory of the trainer's hand movement in the preceding three imitation trials. Error bars represent one standard error of the mean

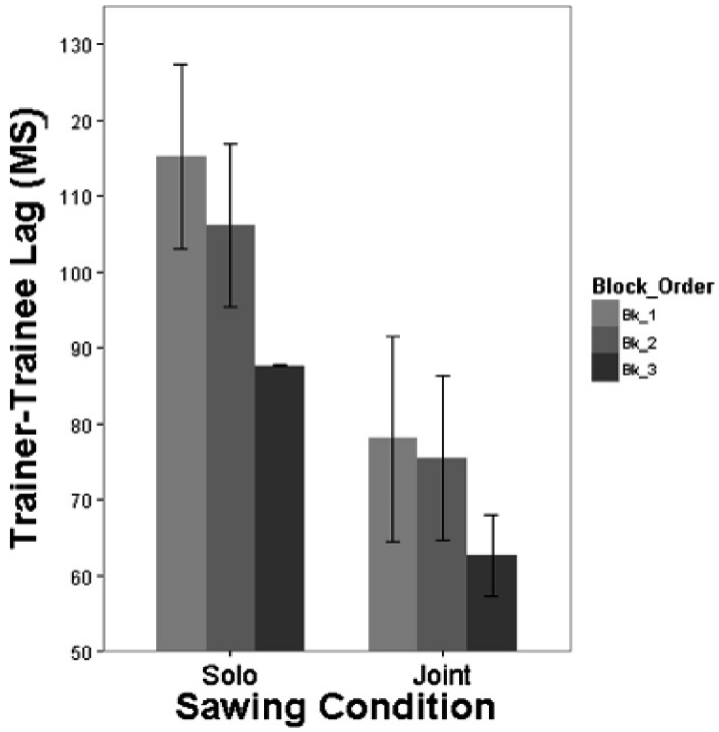


Fig. 18.5 The estimated mean time lag of the participant's imitation movement relative to the trainer's modeling movement during the three imitation trial blocks (bar colors). The Joint participants (right) outperformed the Solo participants (left) in trailing closer behind the trainer during practice. Error bars represent one standard error of the mean

The spatial synchrony advantage of the Joint participants does not come at the expense of temporal lag. That is, the participants in the Joint condition, compared to those in the Solo condition, were, on average, trailing at a shorter lag behind the trainer as they attempted to imitate the trainer's left-hand movements (Fig. 18.5). This finding provides clear evidence that participants in the Joint condition can more quickly predict the experimenter's hand movements, as suggested by the mirror neuron hypothesis.

On the three free production trials, only the participant's mouse coordinates were sampled, as the experimenter put down her mouse and asked the participant to attempt to produce the sequence from memory (in a window of five seconds). For these free production trials, the LCC analyses were computed using the participant's mouse y-coordinates and the trainer's y-coordinates averaged over the three prior imitation trials. Data from the free production trials are depicted on the right-hand side of Fig. 18.4. As is evident in the figure, participants in the Joint condition were better at freely producing the

sequence. This advantage was evident at the first free production trial, and it was maintained thereafter. Thus, these data provide clear evidence that joint action in Phase 1 candle cutting improved social learning (not just imitation) in Phase 2.

Does the enhanced learning reflect increased liking of the trainer (e.g., Wiltermuth & Heath, 2009), or does it represent a change in a JBS or mirror neuron system? The answer is provided by the data from the transverse component, which is the component of the task that was ***not*** modeled by the trainer (see Fig. 18.6). First, there was a reliable main effect for Block. That is, the mean transverse deviation became smaller over the three blocks, so the participants were learning to adjust to the magnets. Second, there was a reliable Block by Box Zone interaction. That is, the change in mean transverse deviation was greater in the no-magnet zone than in the magnet zone; the participants learned where the magnet was and how to respond to it. Third, there was negligible evidence for main and interaction effects for Sawing condition. That is, the zone-sensitive change in learning the transverse component was statistically equivalent in the Solo and Joint conditions.

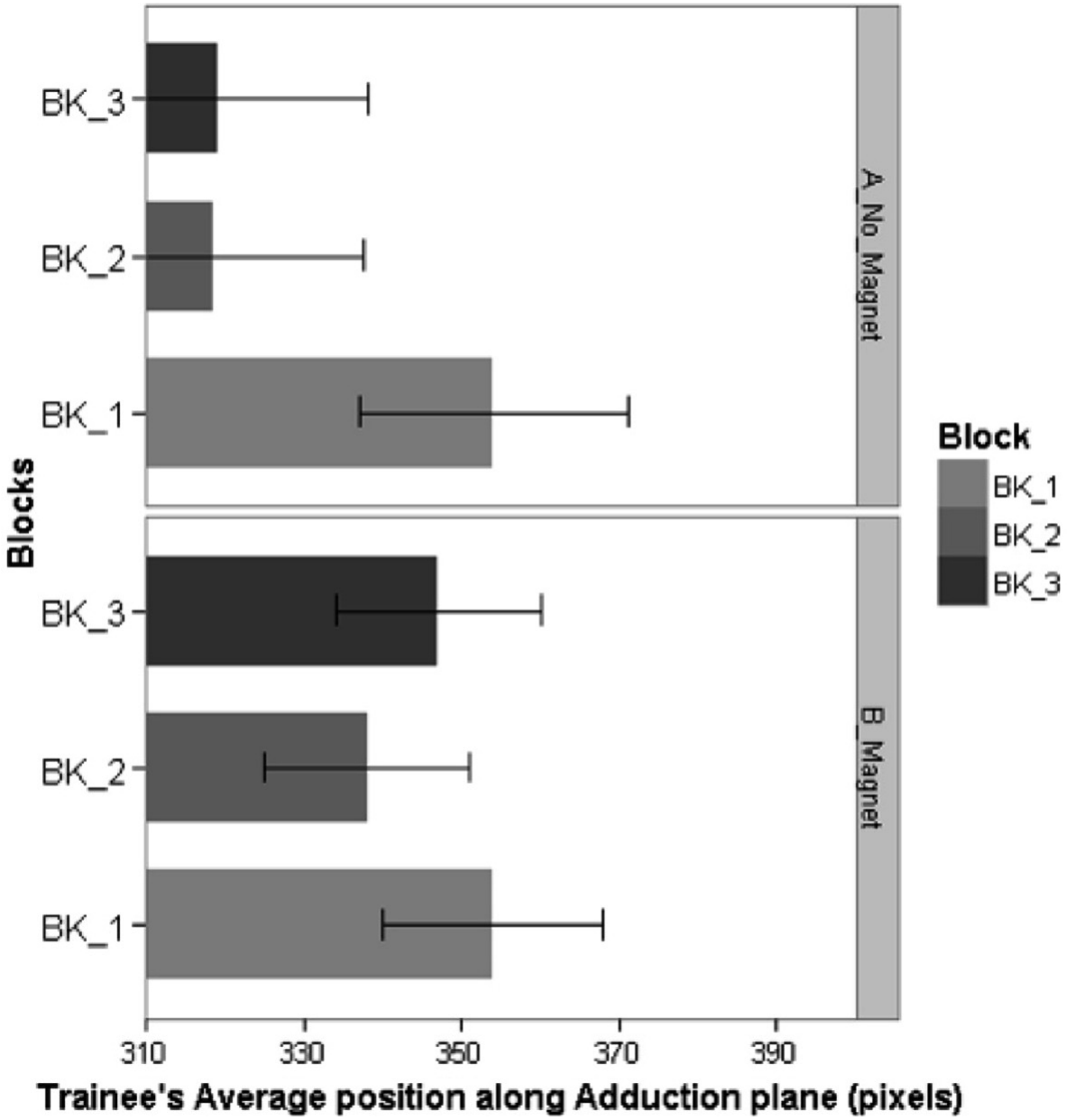


Fig. 18.6 Mean deviation of participants' hand along the horizontal axis in the Magnet zone (lower panel) and No-Magnet Zone (upper panel) of the box. Bar colors represent imitation trial blocks, collapsing over Sawing condition. All participants gradually adapt to the magnetic force field by applying position-sensitive adduction force. Error bars represent 1 standard error of the mean

These three results are contrary to the hypothesis based solely on the increased liking of the experimenter. Synchronous action does induce greater liking (Wiltermuth & Heath, 2009), and we demonstrate an increase in felt self-other overlap in the Joint condition of our third experiment. However, if the enhanced learning seen in Figs. 18.4 and

18.5 were due exclusively to increased liking in the Joint condition, we would expect to see enhanced learning of both the sagittal (modeled) and transverse (non-modeled) components. In contrast, there is no enhanced learning of the transverse component in the Joint condition.

Neurophysiological Evidence that Joint Action Modifies the Mirror Neuron System

What is the neurophysiological substrate of the enhanced learning in the Joint condition? According to Gallese (2005) and Uddin et al. (2007), it is likely to be a strengthening of a mirror mechanism. To test this hypothesis in the context of joint candle-cutting, we used mu-desynchronization to index changes in the motor mirror system (see Fox et al., 2015). Using EEG over the motor cortex (measured using C3 and C4 electrodes), the mu rhythm corresponds to power in the 8–13 Hz frequency band. When the motor cortex is relatively quiescent, mu power is at its maximum. It is as if the neurons are waiting for something to do (i.e., waiting to produce an action), and while waiting, they fire synchronously across the motor system. When a particular action (say, moving the arm to cut a candle) is produced, the motor system is differentially engaged: those neurons controlling the arm are engaged, whereas those controlling the legs and trunk are not. In this case, the mu rhythm ***desynchronizes***, and mu power is reduced. Importantly, the mu rhythm also desynchronizes when simply watching another person act. Because the mu rhythm is sensitive to the actions of other people, it has been used as an index of the motor mirror system activity (Fox et al., 2015). We also measured power in the alpha band (also 8–13 Hz) over the occipital cortex using electrodes O1 an O2. Doing so allows us to determine if the changes in the EEG signal due to cutting conditions are specific to the motor cortex.

We conducted two EEG experiments, one with 52 participants and replication with 46 participants. The two experiments were very similar except in two regards. First, in one of the experiments, there were two versions of the Solo condition: one in which the participant cut candles while the experimenter watched, and one in which the experimenter cut candles while the participant watched. Because the

data were very similar in these two Solo conditions, we dropped the condition in which the experimenter cut candles in the replication experiment. Second, in the replication experiment, we included a measure of felt closeness to the experimenter before and after cutting candles.

There were three phases in the experiments. In the first phase, EEG data were recorded for three 15-s epochs: while the participant moved her fingers, while watching the experimenter move her fingers, and when the participant fixated at a spot (this order was counterbalanced). The fixate condition serves as a baseline for general activity in the motor cortex, and the first phase of the experiment serves as a baseline from which to measure brain changes due to cutting candles. In the second phase, participants were randomly assigned to a Joint or Solo condition. In the Joint condition, the participant and the experimenter jointly cut candles for five minutes as in the first experiment. In the Solo conditions, only one person cut the candles for five minutes while the other watched. The third phase was identical to the first phase so that we could examine changes in the EEG (from Phase 1 to Phase 3) due to Joint or Solo candle-cutting in Phase 2.

We visually examined the 15-s EEG recording epochs and determined that the first six seconds seemed most critical for assessing our hypotheses. This ad hoc approach is problematic (see Vul, Harris, Winkelmann, & Pashler, 2009), which is why we performed the replication experiment also using the first 6 s. At each electrode, we subtracted power in the 8–13 Hz frequency range in each individual's fixation trials (predicted to be large) from power in each individual's movement trials (predicted to be smaller). Thus, increasing mu-desynchronization is reflected as larger negative numbers.

The data of greatest interest are presented in Fig. 18.7. These data are from the Joint condition with the central (motor cortex) electrodes. Note the increase in mu-desynchronization for the C4 electrode from the pre-test to the post-test (a difference of −0.645 units). This difference was not apparent for the Solo-Experimenter condition (a difference of −0.139) nor for the Solo-Participant condition (−0.136).

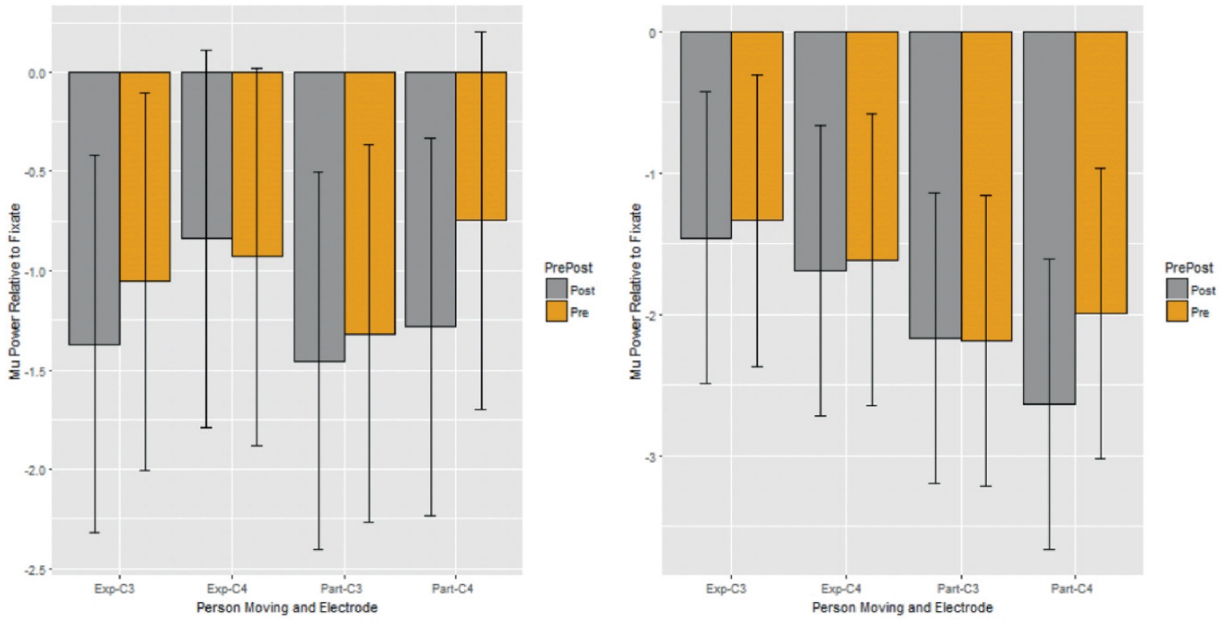


Fig. 18.7 Left: Results from the Joint condition of the second experiment. Right: Results from the Joint condition of the replication experiment. Pre = pre-cutting; post = post-cutting; Exp = experimenter moving; Part = participant moving. Error bars indicate the 95% confidence interval

Now, let's consider five predictions from the hypothesis that joint cutting in Phase 2 modifies the motor mirror neuron system as measured in Phases 1 and 3. First, there should be greater EEG mu-desynchronization after cutting compared to before cutting. Some evidence for this prediction is depicted in Fig. 18.7 in that the gray bars (post-cutting) are generally more negative than the orange bars (pre-cutting). Second, the change in mu-desynchronization should be greater for participants in the Joint condition compared to those in the Solo conditions. In fact, statistically significant effects were only present in the Joint condition (Fig. 18.7); there were no significant effects in either of the Solo conditions. Third, the change in mu-desynchronization should be most noticeable when recording from the right motor cortex (C4 electrode), that is, the area of the brain used to model the experimenter's left hand that was used in joint cutting. This effect is evident in both experiments (both sides of Fig. 18.7). Fourth, the changes should be more evident over the motor cortex (C3 and C4 electrodes) than the occipital cortex (O1 and O2 electrodes). In the analyses of the occipital electrodes, there were no significant effects of the PrePost variable nor any interactions with the PrePost variable.

The fifth prediction is perhaps the most important: Increases in mu-desynchronization should be found when the participant is looking at her own (left and right) hands and when looking at the experimenter's (left and right) hands. However, as can be seen in Fig. 18.7, the effects of the PrePost variable at the C4 electrode are only evident when the participant was moving her own hands ("Part-C4" in the figure), not when she was looking at the experimenter's moving hands ("Exp-C4"). On the face of it, the failure to find an effect when watching the experimenter move is evidence against a mirror neuron hypothesis. There is an alternative, however. Perhaps, the neural signature of the increase in the motor mirror system activity is subtle after only five minutes of joint activity. For example, to demonstrate plasticity in the motor cortex due to direct activity, Classen et al. (1998) had participants engage in that activity for 30 min, and Catmur et al. (2007) used 864 training trials. When there has been little direct activity (e.g., only five minutes of joint activity), the complete neural signature of mirroring may be evident only when the motor mirror system is further activated. That additional activation may be from the participant literally moving her own hand (as in these two EEG experiments) or by some other mechanism, such as transcranial magnetic stimulation (Fadiga et al., 1995, 2002). Thus, we tentatively conclude that the data provide some support for the hypothesis that joint action modifies the motor mirror neuron system.

In the replication experiment, the last 19 participants (9 Joint and 10 Solo) completed a measure assessing their perceived closeness to the experimenter—the inclusion of the other in the self (IOS) scale—before and after candle-cutting. The IOS scale is a one-item measure of closeness in which participants are asked to select from seven pairs of circles (in each pair the circles are labeled "Self and "Other") varying in the extent to which they overlap. This scale has been shown to correlate significantly with longer closeness inventories (Aron et al., 1992) and is commonly used in research on synchrony (e.g., Tarr et al., 2016; Tunçgenç & Cohen, 2016; Vacharkulksemsuk & Fredrickson, 2012). The primary data are in Table 18.1. The effect of PrePost was significant, and there was a significant PrePost x Condition interaction: After Solo cutting, the closeness measure increased by only 0.1 units, whereas after Joint cutting the closeness measure increased by 1.1

units. That is, joint cutting signiﬁcantly increased the felt closeness to the experimenter as measured by the IOS scale.

Table 18.1 Mean closeness scores (and standard deviations)

Cutting condition	Pre-cutting	Post-cutting
Joint	2.11 (0.99)[a]	3.22 (1.39)[a]
Solo	2.50 (1.96)	2.60 (1.84)

[a]These two means are signiﬁcantly different from each other at alpha = 0.05.

Discussion and Implications

Joint action produces a type of entanglement: People confuse stimuli near a partner's body with stimuli near their own (Soliman et al., 2015); one's own motor output is affected by the motor output of the partner (Soliman et al., 2015); and in the ﬁrst experiment reported in this chapter, we demonstrate that one member of the dyad is particularly good at imitating and learning from the other member of the dyad. The results further suggest that this entanglement is not solely the result of conscious cognitive or affective processes; instead, it involves the motor system. We know this because the improvement in learning is only for aspects of the task speciﬁcally modeled by the experimenter (the sagittal movements) and not those aspects of the task that the experimenter did not model (the transverse movements).

The two EEG experiments test a more speciﬁc motor account based on a mirror mechanism (Gallese, 2005; Mukamel, et al., 2010; Rizzolatti & Sinigaglia, 2016). Mirror neurons are active both when a person takes action and when the person observes similar action. Furthermore, both the macaque and the human motor mirror systems are malleable (Cook et al., 2014; Umilta et al., 2008). Thus, we propose the following explanation for the beneﬁt of joint action on social learning: In the Joint condition, the participant pays close attention to the experimenter's left-hand movements (the hand controlling the wire) to anticipate and coordinate with the experimenter's movements. Given the extended temporal contiguity of the sight of the

experimenter's hand and the participant's own motor output, the participant's motor mirror system that controls the participant's left hand is strengthened and adapted to be a more accurate model of the left hand of the experimenter. It is this ability to more closely model the experimenter's left hand (as if it were the participant's own left hand) that results (a) in better imitation, (b) at a shorter lag, (c) with more successful free production of the movement, (d) in increased closeness between the participant and the experimenter, and (e) in an increase in mu-desynchronization. In addition, this proposal is consistent with our previous work on the JBS demonstrating that behavioral manifestations are stronger on the participant's left hand than the right hand.

Nonetheless, one expectation derived from an adaptation of a motor mirror system was not met. Namely, the increase (from pre-cutting to post-cutting) in mu-desynchronization in the C4 electrode should have been evident when the participant was watching the experimenter's hands as well as when watching her own hands. There is very little evidence for an increase in mu-desynchronization when watching the experimenter's hands (see Fig. 18.7). As suggested above, perhaps the neural signature of the increase in the motor mirror system activity is subtle after only five minutes of joint activity.

Implications for Social Interactions and Closeness

Given that joint action adjusts the JBS and mirror neuron system so that A can better understand and predict B's behavior (and leads to greater felt self-other overlap with B, as in Table 18.1), one might speculate that joint action would also affect the perceived quality of close social relations. According to the self-expansion model, closeness involves an overlap in the knowledge structures representing oneself and close others (Aron, Lewandowski, Mashek, & Aron, 2013), which may be observed experimentally through self-other confusion (Aron et al., 1991; Soliman et al., 2015). For example, Mashek et al. (2003) provided participants with three distinct sets of traits. Each set was categorized as true or not true of (a) themselves, (b) their best friend, or (c) an equally familiar but closer target (e.g., a parent). Participants

then completed a surprise recognition test, indicating who the rated target had been for each trait. Confusion was most common between the self and close others—relative to equally familiar but less close others—even when controlling for self-reported similarity.

In a similar vein, Aron and Fraley (1999) found that participants more quickly categorized traits as true or not true of themselves and made fewer errors when the presence or absence of a trait was shared with a romantic partner (that is, when the trait was true or not true of both oneself ***and*** one's partner); importantly, an index combining differences in reaction times and errors for shared and unshared traits signi cantly correlated with self-other overlap on the IOS scale. Other research suggests that perceived self-other overlap as measured by the IOS scale mediates the relationship between empathic concern and helping (Cialdini et al., 1997), affects situational and dispositional attributions (e.g., Waugh & Fredrickson, 2006), and correlates signi cantly with the number of plural pronouns used (e.g., "we" and "us") when describing one's romantic relationship (Agnew et al., 1998).

Aron and Aron (1996) suggest that the metaphor of including others in the self may guide the generation of subsequent hypotheses. In this vein, we predicted and found an increase in closeness when participants coordinated in a joint-sawing task (see Table 18.1), which we interpreted as a precipitator of bodily inclusion through the formation of a JBS. This nding suggests that synchronous ***coordination***, not just synchronous physical mimicry, may facilitate increases in self-perceived closeness.

The connection between coordination and closeness may also be relevant for research on romantic relationships. Engagement in coordinated activities has been shown to improve passionate love (Aron et al., 2000) and relationship satisfaction (Aron et al., 2002), but these ndings have been attributed to task features such as novelty, challenge, or arousal (Lewandowski & Aron, 2004). Although we did not examine love or relationship satisfaction, our results suggest that manipulations of closeness do not require any such features. That is, the Joint and Solo conditions likely involved the same degree of novelty, and participants remained quietly seated (i.e., unaroused) while cutting candles in both conditions. Although it is possible that the task was more challenging in the Joint condition, no participants

experienced visible difficulty or requested assistance while performing the task in either condition. Thus, some forms of physical coordination appear to promote closeness even in the absence of novelty, arousal, or challenge.

Implications for Teaching

Good pre-school teachers often begin the day with songs and clapping, dancing, or other activities which may be viewed as joint actions. We propose that these activities may establish a JBS and thereby improve social learning. This JBS may help to establish rapport, as our IOS data in Table 18.1 imply, and facilitate direct motor instruction, as we found in the first experiment.

Furthermore, other forms of social learning may be impacted because of the change in the mirror neuron system. For example, work by Ping, Goldin-Meadow, and Beilock (2014) suggests a mechanism through which a JBS may facilitate language comprehension. Ping et al. demonstrated that gesture is understood using the motor system. Thus, if a student's motor system is more attuned to that of the teacher, then the student will be better able to simulate the teacher's gestures and better understand the teacher. As an example, gesture plays an important role in learning mathematics. A simple sweep of the hand under one side of an equation and then the other side can help students to understand the meaning of the equal sign (Alibali & Nathan, 2012; Alibali et al., 2011). To the extent that a teacher establishes a JBS with the students, then the students may become better able to track and learn from the teacher's gestures, and the teacher may become better able to assess learning from the student's gestures.

Implications for Rehabilitation

Mechanisms of imitation and social learning play an essential role in skill learning (Higuchi et al., 2012; Stefan et al., 2008), and they have been implicated in the remediation of neuropsychological deficits, such as ideomotor apraxia and poststroke hemiparesis (Buxbaum et al., 2000; Franceschini et al., 2010). The major result of Experiment 1 is that forming a JBS through joint action improves subsequent learning

from a partner. Consequently, a short burst of joint activity (e.g., five minutes) between a rehabilitation therapist and a patient may substantially improve the patient's ability to imitate and learn from the therapist.

In summary, we have demonstrated several novel effects of joint action as well as replicating other effects reported in the literature. Specifically, joint action enhances (a) accurate imitation of one's partner, (b) social learning from that partner, and (c) closeness to that partner. Additionally, our data are largely consistent with the hypothesis that these effects result from changes produced by the joint action in a mirror mechanism. These results may have important implications for physical therapy, teaching, and bonding.

Acknowledgement

Tamer Soliman was supported by an ASU Dissertation Fellowship, A.K. Munion was partially supported by a grant from the ASU Barrett Honors College, and Arthur Glenberg was partially supported by National Science Foundation Awards 1,020,367367 and 1,324,807807. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies. We thank Annette Marino who developed much of the programming needed for the EEG experiments and assisted in data collection.

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Footnotes

1 Full results are available from glenberg@asu.edu. Unless otherwise noted, described effects are significant at $p < 0.05$.

© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_19

19. Take a Walk on the Cultural Side: A Journey into Embodied Social Cognition

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Cultural assumptions, values, and attitudes are not a conceptual overlay which we may or may not place upon experience as we choose. It would be more correct to say that all experience is cultural through and through, that we experience our "world" in such a way that our culture is already present in the very experience itself.
Lakoff and Johnson (1980, p. 57).

Abstract
According to current embodied cognition models, sensorimotor experiences play a critical role in cognition, including social cognition. Since our bodies are embedded in a sociocultural context, it is likely that the link between bodily states and cognition is shaped and constrained by culture. Here we argue that culture affects embodied cognition through three distinct means: (1) the physical environment and the affordances it offers, (2) cultural values and conventions that encourage certain sensorimotor experiences while discouraging others (such as body postures of submission or pride, smiling, hand-washing, and touching), and (3) cultural differences related to language, including metaphors and script direction. The present review is not meant to be exhaustive, but it offers selective insights into the paths through which diverse cultural environments shape embodied

cognition. The chapter also discusses possible future venues for research on cultural embodied cognition.

Keywords Affordances – Social cognition – Culture – Cognitive processes – Nonverbal behaviors – Verbal behaviors – Language – Social communication

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Social psychologists have always assumed that cognition is situated and action-oriented and that the presence of others affects thoughts, feelings, and behaviors (Ross et al., 2010; Zajonc & Markus, 1984). Human beings vary in the way they use their body in relation to and with others and their bodies not only reflect, but also determine, what is active in their mind at any particular time. Along such lines, the growing field of embodied cognition (Barsalou, 1999; Wilson, 2002) builds upon the general notion that bodily experiences and sensorimotor capabilities are integral parts of mental representations and cognitive processes. Several scholars have recognized the importance of the body and its involvement in social interactions, with thoughts and feelings envisaged as closely linked to sensory experiences and bodily states (Barsalou, 2008; Niedenthal et al., 2005; Zajonc & Markus, 1984).

Embodiment theory is commonly tested by experimentally inducing bodily experiences associated with a particular valence or psychological state, then observing the mental representations that form as a consequence. For instance, people holding a pen between the teeth so as to activate the muscles involved in smiling tend to evaluate cartoons as funnier (Strack et al., 1988). Importantly, even the mental representation of abstract concepts such as “success” has been shown to be affected by bodily states, often through metaphors involving the body, such as “moving forward” (Robinson & Fetterman, 2015; for a theoretical review of the embodiment of abstract concepts, see Borghi et al., 2017). Whether or not the embodiment approach can be considered as a theory has been subject to lively debate. Yet, the pivotal force of the embodiment approach, much like Gibson’s (1986) affordance model, has been to direct our attention to the often forgotten role of bodily experiences in cognition.

In this chapter, we will examine the question of whether and through which processes embodied cognition is moderated by culture. Culture is a slippery concept that includes variations between and within nations. Here, we adopt Hofstede's broad definition of culture as "***the collective programming of the mind that distinguishes the members of one group or category of people from another***" (Hofstede, 2001, p. 9). We hypothesize that such "collective programming of the mind" occurs, in part, through an embodied process in which cultures facilitate or inhibit certain sensorimotor experiences, which, in turn, channel mental processes.

While some theories (e.g., Izard & Abe, 2004; Zajonc et al., 1989) have explained bodily movement effects by innate physical structures, others have suggested that the association between sensorimotor experiences and concepts is learned and culturally specific (e.g., Barsalou, 1999, 2008; Niedenthal et al., 2005). According to the first line of argument, there are various reasons to believe that embodied cognition is universal rather than culture specific. The most obvious reason is that human bodies, including their visual and motor systems, are very similar regardless of the physical and cultural environment they inhabit. Thus, embodied cognition may, to some extent, be interpreted as innate and universal (e.g., Wallbott & Scherer, 1986). Human bodies are also subject to common forces, such as gravity, and depend on common substances, such as oxygen, that determine to a large degree what actions bodies can perform. Thus, embodied cognition is subject to constraints that are common to all cultures.

Despite these universal features, one may argue that embodied cognition is moderated by culture and that people experience the body-cognition link in culture-specific ways (Wierzbicka, 1994, 1995). At the most general level, the body is not the ultimate grounding of experience, but the result of historical experiences and cultural practices (Merleau-Ponty, 2004). Before representing knowledge, we already embody it. Similarly, Soliman and Glenberg (2014, p. 217) define culture as "a repertoire of bodily modes of interaction" that lay the ground for culture-specific knowledge. Put simply, body and cognition are always encultured; therefore, it is hard to imagine experiences that are truly "culture-free".

Despite the theoretical and practical relevance of a culture-speci𝕗ic approach to embodiment, this perspective has been largely neglected in the empirical literature. There is conspicuous evidence for cultural differences in nonverbal expressions (such as body postures, gestures, or interpersonal distance), and for the link between bodily states and cognition. We also 𝕗ind a corpus of literature that argues for the in𝕗luence of culture on cognitive processes, yet studies that speci𝕗ically and simultaneously test the three elements in a unique paradigm (see Fig. 19.1) are quite rare. In the present chapter, we will argue the need for an integrative approach to cultural embodied cognition and speculate on this triangle by inferring possible processes or effects to be tested in future studies.

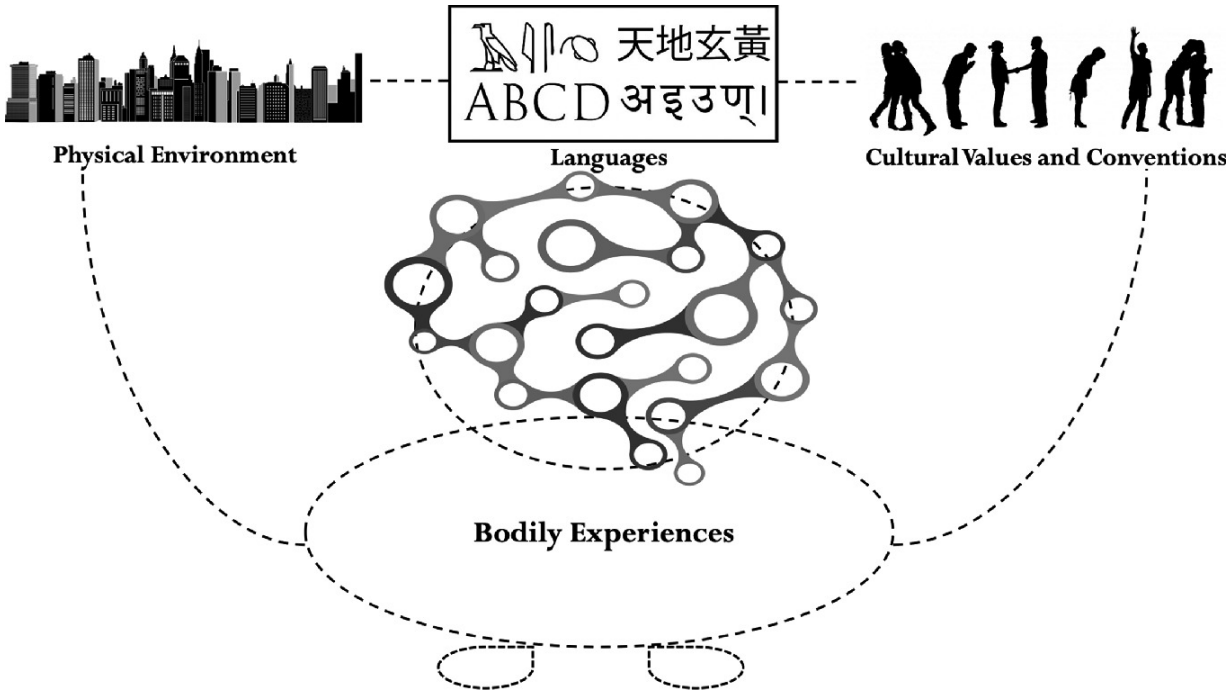


Fig. 19.1 An integrated approach to cultural embodied cognition

We will further argue that there are at least three ways in which culture guides or restraints embodied cognition. The 𝕗irst concerns the ***physical environment*** created by each culture, including architecture, the layout of cities, homes, institutional buildings, and the like. The second concerns ***social norms and conventions*** that prescribe certain motor actions while discouraging others. Such norms may be very broad as in the case of levels of interpersonal distance, touch, gaze or

smiling considered appropriate in a given culture. Alternatively, cultures may allow or prohibit very specific behaviors such as “eating with one’s left hand” or “stepping on books”. The third set of elements concerns specific features of ***language.*** For instance, our knowledge of abstract concepts is strictly linked to metaphorical language that varies across languages (Lakoff & Johnson, 1980). Similarly, writing systems exert a systematic influence on cognition through the repeated performance of specific visuomotor actions. Although we are unable to provide a comprehensive review of the literature, in this chapter, we will illustrate each of these three realms through examples that provide empirical support for, or at least are compatible with, the hypothesized process. We will close the chapter with a brief discussion of possible future research that could test the moderating function of culture in embodied cognition in more stringent ways.

The Built Environment

The close link between culture and the built environment has long been acknowledged (Levi-Strauss, 1963) and continues to be debated in anthropology and ethnology (Vellinga, 2007). The built environment not only reflects culture, but also shapes and maintains culture-specific structures, social identities, and behaviors. An example is Levi-Strauss’ (1963) work on House Societies where political and kindship relations are organized around physical buildings that define the social identity of the group and provide continuity across generations, quite independently of the membership of specific individuals at any given time.

Although architecture and design are becoming increasingly uniform in modern societies, traditional architecture still shows remarkable variations in building materials (e.g., wood vs. cement), building shapes (e.g., favoring round vs. square shapes in dwellings), seating arrangement (e.g., on the ground vs. on chairs), surface textures, and the like. Even current urban areas, where the majority of the world’s population lives, vary strikingly in density, walkability, compactness, enclosure, color, height, complexity, and on an infinite number of additional dimensions that provide different visual, auditory, olfactory, and haptic stimulations and solicit distinct

behavioral responses. Thus, every culture creates, through specific artifacts such as houses, furniture, public squares, malls, bicycle routes, etc., affordances that invite certain behaviors while discouraging others. For instance, Venice "invites" its citizens to walk almost every place they want to reach, whereas Los Angeles "invites" its citizens to spend over 250 h per year sitting in their cars just to commute to work (Washington Post, 2019).

Building on Gibson's (1986) work, the concept of ***affordance*** has had a long tradition in environmental and ecological psychology and has regained importance when embodied cognition models emerged over the last decades (as an example of the revival of ecological psychology, see Meagher, 2020). According to Gibson, physical environments offer species-specific action opportunities, called affordances, that shape behavior and perception. Environments become walkable, sittable, graspable, climbable, etc., to the degree to which the environment matches the body of the person or animal inhabiting it. For instance, a baby bouncer allows and invites toddlers and possibly small dogs, but not adult humans, to climb inside and enjoy the movement. If cultures create affordances that invite specific sensorimotor experiences, will these also affect cognition? Or put differently, do cultures affect embodied cognition by creating culture-specific physical environments?

There is now growing evidence that physical environments can affect not only well-being and stress regulation, but also cognitive processes such as reaction times, likelihood estimates, and future orientation. To cite only a few examples, the psychological benefits of visual contact with nature are well substantiated and have motivated architects and designers to increasingly include natural elements in buildings (for an overview, see Grinde & Patil, 2009). In this connection, hospital buildings with views of nature tend to have restorative effects, facilitating healing and creating a buffer to stress (e.g., Ulrich, 1984; for a review of the biophilic design hypothesis, see Gillis & Gatersleben, 2015). Exposure to nature also boosts creativity by allowing attention restoration and mind wondering (Martínez-Soto et al., 2013; Williams et al., 2018). Thus, the great variability in green areas per capita across and within countries may have a number of important psychological implications.

A similar argument can be made for architectural styles. As an example, ***high-style*** architecture, also known as Structural Expressionism, with its "cold" building materials and large volumes, may be experienced as intimidating, making the person feel small and insigni cant, which may, in turn, affect cognition. Such attributes have been capitalized on in the form of courthouse architecture. Compared to smaller and "warmer" historical courthouses, large high-style courthouses were found to make people more pessimistic about the outcome of a trial (Maass et al., 2000). Similarly, the exposure to very tall (vs. lower) buildings produces a feeling of awe, combined with behavioral immobility ("freezing" response), which, in turn, produces a slowdown in reaction times (Joye & Dewitte, 2016).

Another aspect of built environments that differs remarkably across cultures and geographical areas is population density, ranging from very densely populated urban areas (e.g. Macau) to low density places such as Mongolia. Even cities of comparable population size (such as Manila and Damascus) may have very different population density, as a function of distinct urban planning strategies. Recently, population density has received renewed attention in psychological research (Sng et al., 2017). Even after controlling for other relevant variables such as GPD and population size, Sng et al. nd that, as density increases, people become more future-oriented. They delay reproduction, have fewer children, invest more in education, etc. Population density is also one of the ecological conditions that, according to Gelfand and collaborators (Gelfand, 2012; Gelfand et al., 2011), is predictive of more stringent social norms and less tolerance toward deviant behavior (***tight*** vs. ***loose*** cultures). Although the exact psychological processes driving the greater future orientation, long-term planning, and normative regulations in high-density conditions remain to be understood, it is not unlikely that embodied reactions to overcrowding (including overstimulation) may play a role in such phenomena.

Importantly, built environments also exert a remarkable in uence on children's cognitive and social development. Cognitive abilities of infants and children develop in interaction with their physical and social environment, both of which show remarkable cultural variation. As Linda Smith (Smith & Gasser, 2005) puts it "The physical world

serves to bootstrap higher mental functions". One example is child-friendly environments that Kyttä (2004) defines as those that (a) offer positive affordances for children and (b) allow independent mobility. Children growing up in walkable, child-friendly cities (e.g., where car traffic is reduced, like Venice) that allow autonomous roaming from an early age tend to develop spatial abilities much earlier than those living in car-dominated urban spaces (Malucelli & Maass, 2001).

Together, the above lines of research illustrate that (a) cultures create distinct physical environments and (b) such cultural variations in physical environments have tangible effects on people's emotions, cognition, and well-being. However, the roles of embodied experiences linking culture-specific environments to psychological outcomes are underinvestigated, and hence, less well understood. In particular, the link from culture-specific spaces to an embodiment to cognition is rarely investigated within a single research paradigm. Although there is now growing interest in the role the body plays in culture-environment interactions (for an overview see, Raymond et al., 2018), the empirical evidence linking cultural artifacts, body, and cognition is currently rather limited.

The one notable exception is research on environmental complexity, suggesting that the physical environment created by each culture, and the actions and sensory experiences it affords, may affect people's cognition in systematic ways. Urban complexity varies greatly across cultures. Think about the grid plan of many American cities compared to the daedal layout of European cities. Or compare the linear street views of New York City with the intricate street views of Venice or New Delhi, with their winding and densely populated areas (see Fig. 19.2).



Fig. 19.2 Street view of New York City (on the left) and Venice (on the right)

Different authors have argued that urban complexity will train people to pay attention to multiple stimuli and ultimately shape their capacity to integrate focal and background information. A remarkable example is a study by Miyamoto et al. (2006), in which the authors randomly sampled photos from cities in Japan and in the US, finding a much greater complexity of the urban environment in Japan, where urban scenes objectively contained considerably more elements. The authors argued that this greater complexity may encourage people to pay more attention to the environment. In support of this idea, the authors found that both Japanese and US participants paid more attention to context when viewing Japanese rather than American urban scenes. Strikingly, people adapt their visual attention patterns very rapidly to new physical environments, as shown by subsequent eye-tracking studies (Ueda & Komiya, 2012).

The differential complexity of the urban environment, together with the effect it has on attention to context, may help explain why Japanese people, in general, are more inclined to focus on context and to integrate foreground and background information (***binding***), whereas Americans tend to concentrate on foreground objects. Interestingly, such cultural differences in visual processing emerge as early as 3 years of age, with Japanese children perceiving objects more holistically than American children (Kuwabara & Smith, 2016).

Thus, one way in which people from different cultures may develop more holistic versus more analytic styles of thinking (Nisbett et al., 2001) is through the built environment created by each culture. This

interpretation receives support from a set of cross-cultural studies involving, among others, a remote population in Namibia, the Himba, who are considered a highly interdependent culture (Caparos et al., 2012). Interdependent cultures (such as Japan) are generally believed to promote global or holistic rather than local or analytic information processing. The Himba constitute a remarkable exception to this rule and Caparos et al. tested the hypothesis that this may be attributable to their distinctly non-urban living conditions. In line with predictions, the authors observed a shift toward global or holistic processing among those Himba citizens who had moved to urban areas or who visited urban environments frequently. Thus, much like Miyamoto et al.'s (2006) study, this research sustains the idea that the exposure to complex urban environments, characterized by visual clutter, is, at least in part, driving the relatively stable cultural differences in analytic vs. holistic processing.

We are not arguing that architecture is the only, or even the most important, factor in the development of cognitive styles. Countries with particularly heterogenous urban spaces may experience greater visual complexity in other realms as well, including language scripts and cultural artifacts such as websites (Wang et al., 2012). Thus, it is likely that cognitive styles develop through multiple routes, but it remains an intriguing idea that culture-specific holistic (vs. analytic) cognition derives, at least in part, from visual experiences with more complex and cluttered physical environments.

Social Norms and Conventions

The physical environment is not the only way in which cultures shape embodied cognition. Probably the most common path through which culture affects our senses and motor system is through implicit and explicit rules governing our body postures, our gaze, smiling behavior, the distance we keep from others, whether we touch others in social interactions, whether we eat from a shared bowl, and the like. To the degree that such body postures and comportments affect our cognition, cultural norms and conventions should also shape our minds. Here, we will selectively report on five areas of research in which this hypothesis has been tested in cross-cultural comparisons,

namely, gestures of submission and dominance, gestures of pride and shame, smiling, hand-washing, and touch.

Gestures of Submission and Dominance

Many cultures prescribe situation-specific gestures of submission or dominance in social interactions and they may do so in gender-specific ways. For instance, in many European countries until the 1950s, girls were expected to greet adults with a curtsy gesture, bending their legs in an asymmetrical fashion with one foot moving backwards. Boys, instead, were expected to bow their heads. Both actions can be interpreted as gestures of submission from the person of inferior status (here, the child) in a social hierarchy. From an embodied cognition perspective, such socially expected motor actions are likely to activate associated feelings and thoughts of inferiority. These gestures of submission seem to be stronger for girls (vs. boys) as their curtsy gesture involves the whole body, and this may contribute to making girls feel even more inferior than boys when interacting with adults. Although this specific convention has since disappeared in Europe, similar signs of submission continue to be prevalent in many cultures, especially for women, attesting to both temporal and cultural variability of norms regulating body posture.

There is now ample evidence that different cultures value different characteristics and encourage different behaviors. Although the distinction between individualistic versus collectivistic cultures is certainly an oversimplification that ignores the nuances of cultural specificities, overall individuals in many Western nations are seen as independent and separate from one another and are encouraged to express their feelings, self-enhance, and stand out relative to others (Morling et al., 2002). Therefore, in Western cultures, individuals are usually evaluated in terms of their personal influence, achievement, and assertiveness (Zhong et al., 2006). By contrast, in East Asian cultures such as Korea and Japan, individuals are more likely to be seen as interconnected and interdependent, and greater value is placed on the preservation of group harmony rather than on personal achievement. As a consequence, people are culturally expected to display signs of modesty and humility more than in Western cultures

(Crocker & Park, 2004; Markus & Kitayama, 1991; Triandis, 1989). Thus, postures of modesty versus dominance, which are often assumed to be universal, may have culture-speciﬁc meanings.

Following this line of thinking, we suspect that the embodied effects reported among Western samples could take different forms if culture were taken into account. For example, a great deal of Western literature shows that expansive body postures signal power and dominance (e.g., Hall et al., 2005; Tiedens & Fragale, 2003), and that powerful body postures produce increased feelings of power, tolerance for risk, and power-related thoughts (Carney, Cuddy, & Yap, 2010; Goldin-Meadow & Beilock, 2010; Huang, Galinsky, Gruenfeld, & Guillory, 2011; for a review, see Cuddy et al., 2018). Building on this research, Park et al. (2013) investigated whether power-related expansive postures are compatible with both Western and East Asian norms and values and whether they may be experienced differently in different cultures. American and East Asian participants were provided with three types of expansive postures tested in previous research (i.e., the ***expansive hands spread on desk*** pose, the ***expansive upright sitting*** pose, and the ***expansive feet on desk*** pose). The ***expansive hands spread on desk*** and the ***expansive upright sitting*** postures led to greater sense of power than a constricted posture for both Americans and East Asians, whereas the ***expansive feet on desk*** pose led to greater power activation and action orientation only for Americans, but not for East Asians.

Park et al. (2013) suggest that the feet on desk pose may have violated general modesty norms or, more likely, speciﬁc norms regarding placing shoes on a table. The US is probably one of the few cultures in which putting shoes on tables or seats is considered normative; in many Asian cultures, this same behavior is likely to be considered offensive and unacceptable (see, for instance, a diplomatic incident in Israel, 2018, when the Japanese prime minister was served dessert in an aluminum shoe; also see Goyal, Adams, Cyr, Maass, & Miller, 2020, for a discussion on norms concerning shoes). Independent of the precise norm violation, Park et al.'s ﬁndings clearly support the embodied cultural hypothesis according to which the effects of postures are contingent upon both the type of posture and the cultural symbolic meaning of the speciﬁc posture (also see Matsumoto & Kudoh, 1987).

Importantly, the concept of culture is not limited to nations, but can also refer to cultural subgroups such as gender. Men and women may well express power in distinct forms and experience bodily expressions of power differently, in line with gender-related expectations. For instance, Schubert and Koole (2009) showed that male participants making a fist activated an empowered self-concept, both explicitly and implicitly, perceiving the self as being more assertive and socially esteemed. The same effect did not occur among female participants. Similarly, Schubert (2004) found that making a fist activated power-related concepts in both males and females, but only among men was this gesture associated with higher perceptions of control. These gender differences for the same bodily experience can be explained in terms of cultural gender role expectations, where men are culturally expected to use bodily force to gain power and control over others, whereas women are seen as reluctant to use bodily force (also see IJzerman & Cohen, 2011, for a discussion of cross-cultural considerations).

Thus, it is the culture-specific and gender-specific meaning rather than the gesture itself that produces the corresponding mental state. Similar points are also evident in acculturation effects. For example, the tendency to tilt the head (head canting) is interpreted as a signal of submission and is more prevalent in the representation of women than men in artworks (Costa, Mezzani, & Bitti, 2001), therefore, suggesting that visual representations are permeated with bodily cues that perpetuate gender roles. Interestingly, this tendency is modulated by culture. Along these lines, Cardon et al. (2018) analyzed head canting in LinkedIn profiles and, besides replicating stronger head canting among women than men (Tifferet & Vilnai-Yavetz, 2018), the authors also found that American users engage in head canting more often than Chinese users. Importantly, the extent to which gender affected self-presentation was different in the two cultural samples, with almost 60% of women among the American professionals tilting their head in their profile picture, but only 47% of Chinese professional women doing so. Possibly, head canting may not be as meaningful a cue in the Chinese culture. Interestingly, the percentage of females (vs. males) who tilted their heads was higher (81%) among Chinese professionals posting their profile in English, suggesting the use of body signals that

is congruent with the cultural context. The linguistic context, therefore, activated the broader cultural context which also involves specific embodied signals. This example shows that nonverbal behaviors might operate at both encoding and decoding levels: An actor performs a nonverbal behavior (i.e., heat-tilting) in order to be perceived in line with the interlocutor's expectations and s/he does so in line with the cultural-specific meanings attributed to that particular nonverbal behavior.

Gestures of Pride and Shame

Closely related to dominance and submission gestures are bodily expressions of pride and shame. Victory gestures (arms raised above the shoulders, torso pushed out, making a fist) are well studied in athletes, for instance, while crossing the finish line or after scoring a goal. This spontaneous bodily response to victory seems to serve the function to communicate positive emotion and is, indeed, understood by observers as exactly that: a sign of triumph. The social acts of communicating (athlete) and perceiving (audience) victory are embedded in specific bodily movements which represent the abstract concept of success. To which degree are these gestures of pride and their opposite (shame) universal?

Tracy and Matsumoto (2008) compared postural displays of pride and shame in sighted, blind, and congenitally blind athletes from over thirty countries while competing in Olympic and Paralympic Games. Individuals from all cultures displayed the ***same*** bodily components typical of pride (victory) described in the initial example (e.g., raising arms and open chest) in reaction to winning, suggesting that the abstract concept of victory-success is embodied in innate behavioral responses. However, the prototypical posture for shame in reaction to defeat (i.e., chest narrowed and shoulders slumped) was found to be displayed in a culture-specific way. Athletes from individualistic cultures (e.g., USA) were less likely to show these bodily postures as compared to individuals from collectivistic cultures (e.g., Japan), where shame is seen as an appropriate response to social failure. This is not to say that Americans do not ever embody the emotion of shame, but the data do suggest that the suppression of this particular emotion

might depend on 'higher' goals, such as social communication, which make individuals sensitive to cultural codes and values (e.g., regulating public emotions).

Interestingly, also, Tracy and Matsumoto (2008) found the strongest expression of shame among blind athletes from all cultures, suggesting that those who had never seen others suppressing victory and defeat emotions are less likely to be affected by cultural codes concerning expression. Although this study did not investigate cognitive consequences, there are plausible reasons for positing them. For instance, related research has shown that holding prototypical guilt poses (head tilted downwards, slumped shoulders, constricted chest) increases personal and collective guilt and intentions to repair misdoings (Rotella & Richeson, 2013). Thus, it is likely that the cultural differences observed by Tracy and Matsumoto (2008) would have consequences for the thoughts and feelings linked to shame.

Smiling

Another interesting nonverbal behavior that is, at least in part, guided by cultural norms and conventions is smiling. To explore the influence of culture on the social perception of nonverbal behaviors, Krys and colleagues (2016) investigated samples from 42 countries (the GLOBE project: House, Hanges, Javidan, Dorfman, & Gupta, 2004) and examined whether smiling individuals were perceived similarly across cultures. Of course, smiling individuals are usually perceived more positively than non-smiling ones; they are seen as happier, friendlier, more honest, more attractive, and more competent. However, this was not true in 6 cultures involved in the GLOBE project (2004). In fact, Krys and colleagues found that a smiling individual was judged as less intelligent than the same individual with a neutral expression in those cultures that had a high tolerance for uncertainty and ambiguity (scoring low on GLOBE's uncertainty avoidance dimension). Only people in countries seeking predictability interpreted smiling as a sign of intelligence, possibly due to the fact that smiling may signal certainty (Hareli & Hess, 2010). Additionally, authors showed that in those societies in which the level of corruption is high, the trust toward smiling people was considerably reduced. Importantly, the key to

understanding this variability was not geographical (e.g., countries like China and Japan scored differently) nor economic, but cultural.

Together, this and related research suggests that smiling has a different function and signals different characteristics in different cultures. Relatedly, research indicates that smiling is encouraged to different degrees in different cultures. This idea of culture-speciﬁc display rules is supported in both self-report (Matsumoto, Yoo, & Fontaine, 2008; Rychlowska et al., 2015) and observational (Girard & McDuff, 2017) studies. The former line of research suggests that the facial expression of emotions is considered more appropriate in individualistic countries, especially those with a history of immigration. This dynamic presumably occurs due to the fact that the expression of emotions facilitates communication and builds trust, which becomes critical in more heterogeneous societies. This general idea was conﬁrmed by Girard and McDuff's (2017) large-scale observational study on smiling across cultures. Actual smiling was more frequent in countries that are individualistic, have lower population density, and have a history of immigration of heterogeneous populations.

Together, these and related studies show that social norms governing smiling differ greatly across cultures. What these studies do not show is that such norms encouraging or discouraging smiling also lead to corresponding shifts in cognition in the person performing the smile. To close the cycle, we need to look at complementary literature showing that the activation or inhibition of muscles involved in smiling (in particular, the zygomaticus major muscles) do affect cognitive and emotional responses. In particular, research on the facial feedback hypothesis suggests that induced facial expressions (e.g., smiling) create corresponding subjective experiences of emotion (e.g., happiness; see Coles et al., 2019, for a meta-analytic review). Particularly telling is research on emotional display rules enforced by organizations such as hotels or airlines, requiring employees to show friendly facial and bodily displays (including smiling). This kind of "emotional labor" may result in an alignment between facial expression and inner feelings of the employee, resulting in increased job satisfaction and reduced burnout. However, when such superﬁcial displays are clearly in contrast to inner feelings, the resulting effects on

satisfaction may be negative (e.g., Chen et al., 2012). Thus, facial expressions do not automatically and always translate into corresponding psychological states.

Importantly, facial displays such as smiling or frowning may extend to the evaluation of external stimuli, such as cartoons (Strack et al., 1988) and people (Ohira & Kurono, 1993), and may even affect behavior (such as food cravings: Schmidt & Martin, 2017). Moreover, it is known that smiles (and other facial expressions) tend to produce facial mimicry in observers, suggesting that the embodied effects produced in the actor may spread to others (Niedenthal et al., 2010). Although the above findings are supportive of the embodied cognition hypothesis, the complete embodied cultural cognition cycle, from culture to facial display to cognition, is still awaiting systematic investigation.

Hand-washing and Religion

Another motor behavior that has received much attention in the embodied cognition literature is hand-washing, which has related to morality, purity, and guilt. Rules concerning this behavior vary greatly across religions. It is, therefore, conceivable to find religion-specific embodiments due to diverse normative constraints. Cohen and Leung (2009) discussed a recent study exploring the effects of specific bodily gestures on embodied morality with a sample of student participants who identified themselves as Muslim, Protestant, Hindu, or Jewish. Under the disguise of investigating hand temperature and hand–eye coordination, the authors asked unaware participants to perform the motion of hand-washing through rubbing their hands (which should correspond to the act of removing physical contamination). After performing this hand-washing gesture, participants were asked to rate various scenarios by providing their moral stance on purity-related offenses with regard to committing physical contamination acts (e.g., having sex with a chicken before cooking it; wearing the clothes of a child molester) or endorsing blasphemous or other improper beliefs (e.g., saying hateful things against God) along with other scenarios involving autonomy-related violations (e.g., infringing on another person's rights or privacy).

First, across religious groups, participants who embodied the hand cleaning gesture rated the scenarios as more morally wrong as compared to participants who had not performed this gesture, providing evidence for an embodied effect on cognition. More relevant to religion-speciﬁc hypotheses, all four religious groups condemned contamination-related acts when the embodied hand-washing gesture was performed. However, cultural differences emerged when it came to the condemnation of blasphemous and improper beliefs. Here the effects were especially strong for Muslims and, to a lesser degree, for Protestants, probably because these religions most strongly condemn immoral beliefs, which are likened to immoral acts. Similar results were not found among Hindus and Jews. Altogether, the Cohen and Leung (2009) ﬁndings suggest that hand-washing gestures may have primed purity in all religions, but that cultural differences emerged in what was considered pure and moral for each religion.

Social Touch

Finally, cultures differ greatly in the degree to which they allow or encourage interpersonal touch. Starting in the 1960s, a large body of literature has distinguished high-contact (e.g., Latin America, Mediterranean) from low-contact cultures (e.g., UK, Japan). People in high-contact cultures tend to have smaller personal spaces, keep closer distance from others in social interactions, and engage considerably more in interpersonal touch. Also, the areas of the body that others are allowed to touch are, on average, smaller in countries like the UK (Suvilehto et al., 2015). Even infants receive motor and tactile stimulation from their mothers that differ systematically from culture to culture (Carra et al., 2014; Hsu & Lavelli, 2005). Thus, spatial behavior and interpersonal touch are governed by speciﬁc implicit norms in each culture, often deﬁned in rather complex ways (with precise variations depending on gender, status, age, familiarity, context, and the like). These norms tend to be internalized by members of each culture and displayed in a largely automatic way in social interactions.

Over the past decades, the effects of social touch have been investigated in a lively and expanding line of research including both

adult populations (for an overview, see Jakubiak & Feeney, 2017) and infants (for an overview, see Cascio et al., 2019). Social touch has been shown to have remarkable effects on diverse human experiences including well-being, learning, persuasion, intergroup relations, and cognition. In infants, social touch (including skin-to-skin contact and massage) has long-lasting beneficial effects on the physical and cognitive development of the child, including executive function and cognitive control (e.g., Feldman, Rosenthal & Eidelman, 2014). In adults, touch tends to increase compliance, including courtship compliance (Guéguen, 2007), facilitate bonding, strengthen romantic relationships, improve well-being, buffer stress, and even improve intergroup relations by reducing implicit prejudice (Seger et al., 2014).

What is less clear is whether touch produces the same or distinct effects in different cultures. For instance, Suvilehto et al., (2015, p. 138) have argued that the primary mechanism through which physical closeness and touch create and maintain social bonds is universal and biologically determined, but that "cultural conventions may up- or down-regulate the average magnitude of social touching". Taking this argument one step further, one may argue that low-contact cultures (or those with explicit no-touch policies in specific settings such as schools) deprive people from experiencing the positive effects of touch. There is indeed some preliminary for this idea. For instance, Lowe et al.'s (2016) research suggests that children in cultures in which mothers engage more in playful touch may be better prepared to regulate their emotions after stressful situations (such as in the ***still face paradigm*** to which infants were exposed in this study). Other authors have argued that the benefits deriving from touch may actually be stronger in low-contact cultures, exactly because touch is less normative, less common, and therefore, more telling (e.g., with respect to the toucher's affection for the touched: Jakubiak & Feeney, 2017). In the above cases, touch would produce similar effects across cultures, but the magnitude of the benefits deriving from it may differ.

However, theoretically, it is also possible that the same bodily experience of being touched, coming from the same source (for instance an acquaintance), may produce positive reactions (e.g., greater agreement) in some cultures while producing negative reactions in others, thus differing not only in magnitude, but in the

quality of the embodied cognition effect. The same touch that may be considered pleasant and that may reduce stress and improve emotion regulation in high-contact cultures may lead to opposite effects in low-contact cultures. In fact, not all social touch is experienced the same way. What touch conveys and how it is felt and reacted to depends not only on who is performing and who is experiencing it, but also on the meaning it has in a given social and cultural context. Importantly, the cultural environment provides critical information on how touch is interpreted (and hence experienced) and what type of touch should be considered normative or counter-normative. However, to the best of our knowledge, empirical evidence for the culture-specific effects of touch is not easily available at this point.

Language and Writing Systems

Language is arguably the chief vehicle of cultural transmission (Kashima et al., 2014). Over the last years, neuroscientists, cognitive linguistics, and psychologists have addressed the question of whether language is an embodied simulation process to represent knowledge (Foroni & Semin, 2009; Gallese & Goldman, 1998). Prompted by failures to detect embodied effects in word comprehension (e.g., Petrova et al., 2018; Zwaan, 2004), the literature is currently stressing the need to put embodiment in context, arguing that linguistic comprehension is tuned to embodied simulations that are relevant for information processing (Estes & Barsalou, 2018). The context that has so far received most attention is the type of task. Here, we would like to draw attention to a wider context, namely, culture, by suggesting that embodied cognition is likely to be tailored to match the specific demands of the cultural context in which the cognizer is embedded.

Languages vary on an infinite number of dimensions, including vocabulary, phonetics, grammar, and the like, all of which may potentially relate to embodied cognition. In the current chapter, we will focus on two aspects of language that may affect embodied cognition above all, namely, metaphoric language and writing systems.

Metaphorical Language

One of the main challenges of embodiment is abstract concepts (such as democracy, power, justice, God), which are by definition detached from specific bodily experiences. The primary tool bridging concreteness and abstraction is metaphors, which are linguistic and cognitive instruments deeply grounded in culture. Metaphors map complex abstract ***target domains*** (such as 'love') onto simpler and more comprehensible ***source domains*** (e.g., 'journey') that are accessible to our senses. Metaphors not only facilitate the comprehension of abstract concepts, but they also make comprehension possible in the first place (Lakoff & Johnson, 1980). If abstract concepts show greater situational and cultural variations than concrete concepts, as many have argued, then they may be particularly suitable for testing embodied cognition (Barsalou, 2008) or multiple representation theories (Borghi et al., 2017) within a cross-cultural perspective.

Although there is evidence for universal conceptual metaphors across different cultures (Kövecses, 2003), metaphors are, in part, culture specific. For example, 75% of the animal metaphors investigated by Talebinejad and Dastjerdi (2005) were the same in English and Persian, whereas 25% were distinct. Another example of cultural variation even in very basic metaphors is the following: when German-speakers talk about things improving or becoming easier, for instance, after a period of illness, they tend to use the upward metaphor (***es geht bergauf*** / ***it's going uphill***); in contrast, Italians use the downward metaphor for the same concepts (***è tutto in discesa*** / ***it's all downhill***). The apparent contradiction may be explained by the fact that Germans view the scene from an observer perspective, such as when observing a graph of economic development toward a higher point. In contrast, Italians imagine themselves as part of the scene and, of course, going downhill is much less effortful than going uphill.

In the case of emotion metaphors, scholars have proposed the embodied cultural prototype view (Kövecses, 2005), which holds that the conceptualization of emotions across cultures is based on both universal human embodied experiences and more specific sociocultural construal, whereby different cultures highlight different aspects of human experience. As an example, getting attention or being assertive is generally viewed positively in Western cultures, but not in Japan. These differences are reflected in two different metaphors: "The

squeaky wheel gets the grease" and "The nail that stands out gets hammered down first", in American and Japanese culture, respectively (Yu, 2008). Along similar lines, Aksan and Kantar (2008) examined conventionalized love metaphors in Turkish and English. Despite a large number of common metaphorical source domains, the analyses revealed that, different from English speakers who conceptualize love in terms of a collaborative work or a success-oriented journey, Turkish speakers see it mainly as a compelling (almost deadly) force whose intensity is typically measured by the amount of pain it imposes on the self. As another example, Akan (a West African, Kwa language) and English show both similarities and differences with respect to metaphoric expressions for fear (Ansah, 2014).

These findings provide support for the cultural embodied cognition perspective: the similarities in the conceptualization of emotions across cultures may be explained in terms of universal embodied cognition; conversely, the differences shown in the language-specific conceptualizations may be interpreted as cultural filters of universal embodied cognition. Put simply, metaphors constitute a generic schema that gets defined by each culture, such that the metaphors receive unique cultural content in different cultures. Relevant to such points, Matsuki (1995) observed that all metaphors for anger in English can also be found in Japanese. At the same time, she also points out that there are a large number of anger-related expressions that map onto the specific Japanese concept of ***hara*** (literally, 'belly'). This is a culturally-specific concept unique to Japanese culture, and so the conceptual metaphor "***Anger is (in the) hara***" is limited to Japanese (for similar differences in metaphors for anger and happiness between English and Chinese, see Yu, 1995; for a comprehensive overview of cultural differences and similarities in metaphors, see Kövecses, 2005).

Importantly, evidence suggests that enacting metaphors may affect cognitive processes in metaphor-coherent ways. For example, Leung et al. (2012) asked participants to physically enact different metaphors for creativity (e.g., in the case of the "thinking outside the box" metaphor, performing a task while sitting inside or outside a box). Across different metaphors, the authors found an increase in creativity, suggesting that the physical enactment of metaphors may not only activate metaphor-consistent knowledge, but also stimulate

knowledge generation. From a theoretical perspective, such results also suggest the possibility that, at least in some cases, the embodiment serves as a mediator of metaphor-coherent cognition. However, it remains to be seen whether such mediation also occurs in spontaneous behavior—that is, in the absence of an explicit instruction to enact a metaphor.

In a similar vein, Gilead et al. (2015) invited Israeli participants to eat sweet (vs. spicy) food before being involved in a social judgment task. There are reasons to believe that sweet and spicy tastes may be embodied in culture-specific linguistic practices. Words associated with sweetness denote affection and love (e.g., the adjective 'sweet' is used to describe gentle, kind, or friendly people), whereas in China, saying that a person is 'spicy' means that they are easily irritated (Ji, Ding, Deng, Jing, & Jiang, 2013). Despite the innately positive valence associated with sweet foods, and the negative valence associated with spiciness (e.g., Klein, Carstens, & Carstens, 2013), in Israeli culture, attributing the character of spiciness to a person is associated with positive valence (i.e., 's/he is ***Harifa***' means 's/he is a smart person'). On the contrary, sweetness is not always associated with positive traits. For instance, 's/he is ***mataktaka***' (i.e., a Hebrew word to describe sweetness) is associated with a negative trait—namely, inauthenticity. On the basis of Israeli culture-specific linguistic metaphors, Gilead and colleagues (2015) tested the manner in which such metaphors may shape social judgments. The authors found that priming participants with spicy (vs. sweet) taste increased judgments of intellectual competence, decreased judgments of inauthenticity, and increased the overall evaluation of social targets, in line with culture-specific ideas concerning these taste types.

Script Direction

Language links mental representations of abstract concepts to concrete experiences also through a second mechanism: by means of the practical motor activity involved in writing or reading. For example, the font of written words can convey the abstract concept of fluency. Instructions written in ***mistral*** font lead the reader to think that the described task is more difficult (Song & Schwarz, 2008). Further,

whether languages are written alphabetically or ideographically greatly affects children's visual skill development. The massive practice of visuospatial processing required to learn ideograms leads to superior performance among Chinese, Japanese, and Korean children in practically any task related to space (e.g., Demetriou et al., 2005). Thus, the visuomotor experience afforded by different scripts has implications well beyond the simple activity of writing and reading.

In a similar vein, culturally de fined writing and reading habits, such as writing from right to left rather than vice versa, may to some degree determine how we encode and decode the world. In written texts, letters, words or symbols are arranged either horizontally (right–left or left–right) or vertically (top–bottom or, very rarely, bottom–top). Given this variance in writing and reading direction, it is possible that this dimension of language can affect thought differentially. Whether script direction in uences the way in which we communicate, perceive, and perform tasks unrelated to writing and reading has been addressed as part of the theoretical model known as ***Spatial Agency Bias*** (SAB: Suitner & Maass, 2016). The SAB model rests on the general assumption that human action is preferentially envisaged in the direction in which one's native language is written and read (e.g., left to right in English, right to left in Arabic). The SAB is the byproduct of two processes, namely, a visuomotor and a linguistic component. In short, the visuomotor component is determined by scanning habits in line with a culture-speci ic trajectory (e.g., left to right in English but right to left in Arabic), whereas the linguistic component refers to the fact that, in most languages, the ***Agent*** (who performs the action), in standard active sentences, precedes the ***Patient*** (who undergoes the action).

The presence of a rightward spatial asymmetry in cognitive processes has received a great deal of attention in cognitive psychology, including with respect to phenomena such as representational momentum (Hubbard, 2005), number and time line (Santiago et al., 2007), and thematic role assignment (Chatterjee et al., 1995). These ndings were initially attributed to brain asymmetries. However, the emergence of ipped patterns in research involving Arabic and Hebrew (right to left direction) or Mandarin (vertical script) speakers (with respect to representational momentum:

Morikawa & McBeath, 1992, imaginary number line: Dehaene et al., 1993, and timeline: Boroditsky et al., 2011) led to a more functional ***cultural*** hypothesis that attributed spatial asymmetries to writing and reading habits.

For instance, Maass and Russo (2003) found that thematic role assignment (i.e., ***who did what to whom***) varied as a function of writing and reading direction, such that Italians (rightward script) tended to draw the agent of action to the left of the patient, whereas Arabs (leftward script) tended to draw the agent to the right of the patient. Moreover, when considering Arabic-speaking participants who were studying in Italy and who performed the task with either Italian or with Arabic instructions, these participants showed an intermediate bias that was correlated with the number of years spent in a left–right writing country. These findings suggest that spatial bias in imaging of human interactions is a direct function of one's exposure to different scripts. Thus, both initial learning and later exposure to a different script direction is sufficient to change the way people think and represent social interactions (also see Suitner et al., 2017).

According to the SAB model, the attentional and motor asymmetries imposed by script direction lead to a generalized "schema for action" that applies to several socio-cognitive processes (Suitner & Maass, 2016), including imaging and memory. As an example, Maass et al. (2009) found that Italian speakers were more likely to position agentic groups (men and young people) to the left of less agentic groups (females and old people), whereas Arabic speakers showed an opposite pattern that involved positioning the more agentic groups to the right. These findings illustrate the subtle role of SAB even in intergroup relations, whereby a spatial schema of action coherent with script direction is applied, further perpetrating the stereotypical view of social groups. By the same token, the repeated exposure to counter-stereotypical spatial displays (leftward facing men and rightward facing women) can contribute to a change of gender stereotypes (Suitner et al., 2015).

One intriguing aspect of script-coherent spatial asymmetries is that they operate in a subtle way, leaving individuals unaware of the powerful influence that writing and reading habits have on the way they think and perceive the world. Importantly, the habitual

visuomotor activity of reading and writing leads people to not only represent actions, but also abstract social concepts (e.g., agency), in a manner coherent with script direction. When asked to choose which, among four directional arrows (left/right-up/downward), best represented ***agency***, 83% of Italian-speaking participants chose the rightward arrow (Suitner et al., 2015). This last example is crucial for the contribution of the SAB model to embodied social cognition theory because it disambiguates the representation of linguistic metaphors (e.g., agency) from the contribution of the sensorimotor system.

Summary and Analysis

Our brief and selective review of the literature suggests that there are different ways in which culture can shape embodied cognition. Together, this body of research challenges the idea that embodied cognition is universal and culturally invariant. At the same time, most of the cultural effects reported in the chapter are of relatively small magnitude as they necessarily operate within the limits defined by the shape and functions of our bodies and by the universal forces (gravity, air, etc.) to which our bodies are exposed. These commonalities set the limits within which culture may operate.

Although cultural embodied cognition still lacks a unifying theoretical framework, the examples reported here are promising as they illustrate a wide variety of cultural constraints on embodied cognition. Arguably, a possible theoretical proposition may distinguish between two roles that culture may assume in the body-cognition relation, namely, a moderating role (see Fig. 19.3) and a distal cause (see Fig. 19.4). On the one side, different cultures may change whether and how a bodily state or experience affects cognition according to the symbolic meaning that the given culture is assigning to the specific bodily experience, for example, through metaphors and norms regulating interpersonal behavior (such as distance). In this case, culture takes the role of a moderator. However, culture may also assume a distal role by prompting and determining physical phenomena, for example, as related to a specific architectural style or urban design, by employing a specific writing system, or by imposing norms that regulate bodily states and behaviors. In these cases, culture

can be envisaged as a cause of the physical grounding of cognitive appraisal.

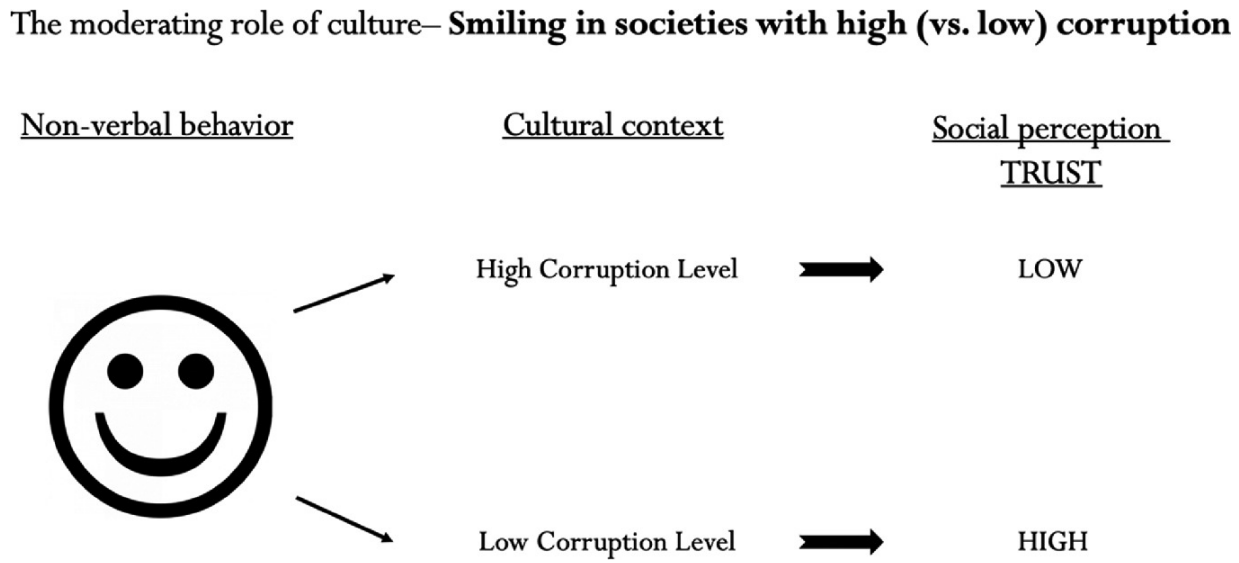


Fig. 19.3 The moderating role of cultural contexts on cognition (i.e., perception)

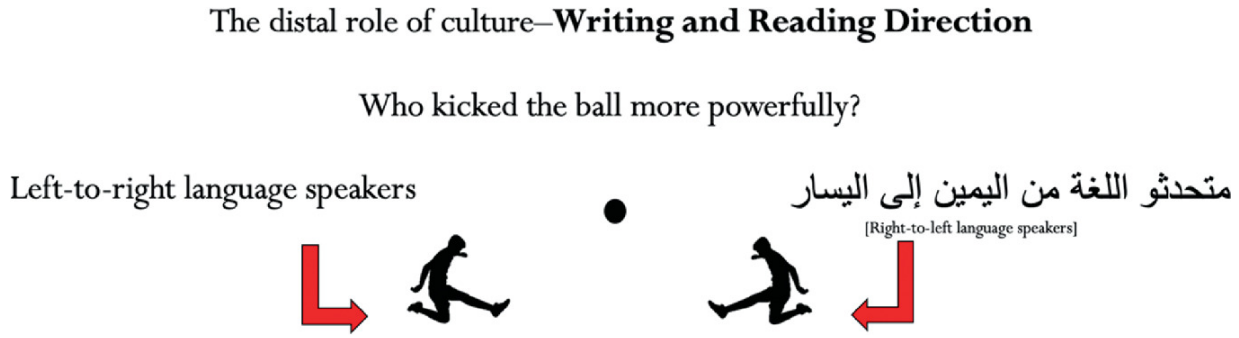


Fig. 19.4 The distal role of culture on cognition (i.e., perception)

Following Cohen and Leung (2009), culture-specific embodied phenomena may roughly be divided into those that create body-cognition links ex-novo (so-called ***totem embodiment***) and those that enforce existing and often hard-wired links between physical comportment and concepts. In the latter case, the principles of embodied cognition are universal, but the strength of the links between visuomotor experiences and cognition are culturally defined. Culture, in the latter case, not only determines the likelihood and frequency of specific sensorimotor experiences, but also how strongly the (pre-wired) link between the body and cognition is going to be experienced and how well it is going to be learned.

At the same time, cross-cultural comparisons in embodied cognition are still relatively rare. The majority of embodied cognition research continues to be conducted on WEIRD samples (Western, Educated, Industrialized, Rich, and Democratic: Henrich et al., 2010) and many cultural variations in embodied cognition are still awaiting empirical exploration. In the last section of this chapter, we will suggest three possible future lines of research, concerning, respectively, the mode of acquisition of embodied cognition, the cultural representation of abstract concepts, and the use of virtual reality to simulate cultural aspects of embodiment.

Mode of Acquisition

If embodied cognition involves a simulation or reenactment of motor and sensory experiences associated with the initial acquisition of the concept (Barsalou, 2008), then culture-specific modalities of acquisition may affect cognition. For instance, if the concepts “chicken” and “baby” are, in some cultures (e.g., agricultural, high natality societies with tight social networks), acquired mainly through direct contact with the object, then visual, motor, and olfactory reenactment can be expected. If, on the contrary, these same concepts are initially acquired mainly through films or cartoons, then the role of the motor and olfactory components during reenactment should be greatly reduced. Although we are not aware of any studies testing the link between culturally determined mode of acquisition and simulation/reenactment, we believe that analyses of this type would provide an ideal test bed for embodied cognition models and their cultural specificity.

The Embodiment of Abstract Concepts

Also, if abstract concepts show greater situational and cultural variations than concrete concepts, as many have argued, then they may be particularly suitable for testing embodied cognition (Barsalou, 2008) or multiple representation theories (Borghi et al., 2017) under a cross-cultural perspective. Accordingly, we suggest a specific focus on abstract concepts, not only with respect to their greater cultural

variation, but also because they are often sustained by metaphors that may vary across cultures.

Virtual Reality

We would like to conclude this chapter in a conceptually provocative way, imagining a potential future situation determined by a progressive leak of cultural aspects in favor of universality of cognitive processes. The remarkable progress in technology provides people with new tools, such as virtual and augmented reality. Besides being suitable for medical treatment for patients suffering, for instance, of neuropathic pain (Austin & Siddall, 2019) or mental health disorders (Freeman et al., 2017), such techniques may offer new visuomotor experiences and generate new patterns of cognitive responses, especially for the younger generations that will have frequent contact with these new technologies.

In this connection, we recently came across a curious case of virtual reality (though not involving humans): A Russian farm (RusMoloko) has ***experimentally*** started to give its dairy cows virtual reality headsets featuring a unique summer ield simulation program to reduce their anxiety, which, in turn, had a positive impact on the quality and quantity of their milk production (https://www.bbc.com/news/world-europe-50571010). The next step could, paradoxically, apply the same treatment to human beings. Based on the evidence that contact with nature has a strong positive effect on subjective well-being (Zelenski & Nisbet, 2014), one may envisage future generations spending time immersing themselves in a natural virtual environment before going to work, which, in turn, might facilitate job performance (Daniels & Harris, 2000).

As with any technological innovation, virtual reality's impact on cultural diversity could represent a double-edged sword. On one side, the use of virtual reality may contribute to a decrement in cultural diversity in favor of an increasing cross-cultural similarity of sensory and bodily experiences. On the ip side, at least in psychological research, virtual reality may provide a unique opportunity for people to experience novel physical environments or encounter new objects that are currently not present in their culture. Such techniques could

allow researchers to investigate the development of new concepts and their link to sensorimotor experiences during learning and during subsequent online or offline processing. Further, such tools would allow researchers to immerse people into other cultures, including their urban and architectonic characteristics, offering an entirely new instrument to simulate culture.

While the authors were writing this chapter, the use of technology was becoming particularly relevant, as the COVID-19 pandemic was at its peak. As a consequence, physical distancing measures were imposed and interpersonal communication was almost entirely mediated through technological devices. We argue here that this new way of communication, which is totally mediated by technological devices, might constitute a new ***culture of communication***. In fact, this communication style greatly affects embodied processes, with potentially important outcomes at the individual, interpersonal, and societal levels. In this type of communication, nonverbal cues are greatly reduced, as tactile, olfactory (and sometimes also gustatory) stimuli are absent. The reduction to two senses—sight and hearing—would then make them particularly central. The need for a clear auditory signal is essential to make communication possible, to the point that any auditory interference is barely tolerated. This prompts the persons who are not speaking to turn off their microphones, which delays any spontaneous taking of the floor, and changes the dynamics of turn-taking in the conversation. Also, with the microphone muted, any para-semantic utterance is missing, hence not allowing feedback between speaker and listener.

Turning to visual stimuli, when video calls are used, faces tend to be seen from a close distance. The literature on face-ism (i.e., the proportion of face to body in the visual representation of a person) suggests that this full-face frame should affect how we perceive people, specifically with respect to power and competence dimensions (Archer et al., 1983). Moreover, online exchanges alter the perceived distance between people, as we are all very near (especially if full-face video is running), yet we are all detached. This lack of fit between the details available on the visual channel and the deficiency on any other channel may create incongruence between the psychological distance of the interlocutor who is physically far away, and the immediately available

communication exchange. In turn, Fujita et al. (2008) showed that a lack of fit in construal level may reduce cognitive fluency and agreeableness. Such mismatching inputs in terms of psychological distance should be further investigated, as distance shapes interpersonal relations in significant ways.

Another key issue regards the lack of a common physical context. In online communication, people do not share the physical surrounding, and hence lack both a real and a metaphorical common ground. We, therefore, argue that from a culture-specific embodiment perspective, online communication offers a very specific setting, which may affect the relation between cognition and physical prompts in a very peculiar way by possibly creating a new cultural way to communicate. In similarity with the culture stemming from deafness, in which embodied cognition has its own specificities (e.g., Miozzo, Villabol, Navarrete, & Peressotti, 2020), we may speculate that online communication creates a subculture that can be characterized in terms of the specificity of the communication channels that are used. We can, therefore, close the circle of Fig. 19.1 by stating that the path from bodily experience to culture is a promising one that warrants extensive attention in future research.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_20

20. Comparing Metaphor Theory and Embodiment in Research on Social Cognition

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Abstract

Social psychologists have expanded the study of mind to recognize various ways in which bodily states and experiences influence social cognition. This development has invigorated interest in conceptual metaphor—a mental mapping that people can use to understand a social concept in terms of a superficially dissimilar bodily concept (e.g., understanding time in terms of moving objects). Taking a step back, though, we see that Conceptual Metaphor Theory takes a different approach to the body than do influential embodiment theories, and there are double dissociations involved: Not all metaphors leverage bodily concepts, and not all embodied influences on social cognition involve metaphor. In this chapter, I illustrate these meta-theoretical distinctions with research findings and show how they help researchers to categorize body-related effects, generate novel hypotheses, and identify conceptual issues regarding mind-body interactions. This analysis is intended to contribute to a taxonomy that differentiates types of embodiment and specifies their roles in social thought and behavior.

Keywords Embodiment – Social cognition – Metaphor – Similarity – Representation

Comparing Metaphor Theory and Embodiment in Research on Social Cognition

Embodiment is Here to Stay, So Now What?

Psychologists rely on metaphors to describe the mind (Bruner & Feldman, 1990), and few have influenced their thinking more than the comparison of cognition to the information processing performed by a digital computer (Gardner, 1987; Gigerenzer & Goldstein, 1996). From this viewpoint, cognition can be described in functional terms as the manipulation of symbolic mental representations according to a set of syntactical rules (the "software") independent of the physical medium in which those processes are instantiated (the "hardware").

Inspired by the computer metaphor, social psychologists began, in the 1970s, to apply the vocabulary of information processing (e.g., encoding, storage, retrieval) to model social outcomes such as person perception, inter-group attitudes, and decision making. These models boasted precision but relied on the assumption that social cognition is largely independent of people's bodies—their direct sensory, motor, and affective interactions with the physical environment.

In subsequent years, researchers discovered that "high-level" social-cognitive processes interact with "low-level" bodily states. Some examples: incidental physiological changes determine emotions (Schachter, 1964; Strack et al., 1988); sympathetic arousal informs attitude strength (Zanna & Cooper, 1974); group concepts are implicitly tied to motoric routines (Bargh et al., 1996); and thinking depends on a limited supply of energy (Baumeister et al., 1998). As a result, the intellectual climate within social psychology shifted, and today no serious researcher believes that people are disembodied computers that passively manipulate symbols in a purely rational fashion.

How, then, should researchers focus their efforts? It is not enough to say that social cognition is embodied; we must also say ***how.*** We should aim to differentiate ***types*** of embodiment and specify their roles

in social thought and behavior. Such a taxonomy would help researchers to:

- Categorize body-related effects by their underlying mechanism.
- Generate mechanism-specific hypotheses that would not follow from treating embodiment as a monolithic construct.
- Bring into focus new conceptual issues.

Delineating a comprehensive taxonomy would exceed space limitations and my intelligence. My contribution is to compare one mechanism—metaphor—to themes and findings in the embodiment literature. I begin by summarizing theory and evidence that metaphor can transfer bodily concepts to structure socially relevant concepts. I then raise two points of caution before conflating metaphor with embodiment in general: Metaphor does not always recruit bodily concepts, and even when it does, its mechanics should be distinguished from those of other embodied influences. I show how these distinctions deliver on the three promises of taxonomy just mentioned.

Background: Bodily Metaphor and Social Cognition

First Theoretical Idea: Metaphor Maps Dissimilar Concepts

Metaphor is traditionally defined as a figure of speech that uses a term for one thing to describe another. Early philosophical views demoted metaphor to a superfluous linguistic ornament or denounced it as the enemy of reason, but a vocal minority of theorists argued that metaphor profoundly shapes how individuals and cultures experience reality (e.g., Jaynes, 1976; Langer, 1942). Building on these insights, Lakoff and Johnson (1980) outlined how people use metaphor to think and not just talk. This account, commonly labeled Conceptual Metaphor Theory, posits that a metaphor consists of two superficially dissimilar concepts, one of which is understood in terms of the other. The concept one seeks to understand is called a target, and it is typically abstract, referring to entities and relations that cannot be observed with the senses. The other concept—a source—is typically more concrete,

referring to entities and relations that are perceptible or clearly delineated.

What does it mean to understand a target "in terms" of a source? Here we come to a key idea: Metaphor operates as a conceptual mapping, defined as a set of systematic associations between elements of a target and analogous elements of a source. The mapped elements can include attributes of one concept (e.g., duration) as well as causal relations and other relational knowledge common to the structure of both concepts. By accessing this mapping, people can draw on their knowledge of a source as a framework for conceptualizing a target, even though the two concepts are unrelated on the surface. Mapping a target onto different sources highlights as well as downplays different sets of target elements, which in turn changes how people understand and relate to the target.

Conceptual Metaphor Theory's account of conceptual mapping is only one of several theoretical positions on metaphor comprehension that have been empirically validated (for a comprehensive overview, see Holyoak & Stamenković, 2018). Still, it offers a provocative answer to a central question in social psychology: What cognitive processes do people use to construct a meaningful understanding of the people, events, and ideas they encounter in the social world? The standard account goes like this: Once people classify a stimulus (e.g., an immigrant) as an instance of a category (Immigrants), they access a repository of knowledge—commonly termed a ***schema***—accumulated through experience with ***similar stimuli***. The schema includes, for example, beliefs about category members' attributes ("Immigrants are lazy") and plans for how to interact with them. Despite its intuitive appeal and ample empirical support, this account overlooks how meaning making involves ***mental leaps***—combining and blending knowledge from different domains (Coulson, 2001; Fauconnier & Turner, 2002; Holyoak & Thagard, 1994). One such leap is the mapping created by metaphor, such as the ***inundation*** metaphor that compares immigrants to water (***tides***, ***waves***) and their perceived impact on one's country to dangerous flooding (***pouring in***, ***seeping in***, ***surging***; Strom & Alcock, 2017). By emphasizing these points, Conceptual Metaphor Theory suggests that, to develop a complete account of the meanings people give to social concepts, researchers need to look beyond

schemas and model how people structure social concepts around ideas that, on the surface, are very different.

Second Theoretical Idea: Metaphor Can Recruit Bodily Concepts

The source concepts of many common metaphors derive from familiar sensorimotor experiences and routine interactions with the physical environment. As an example, Kövecses (2005) observed that people map the idea of intensity onto several bodily states, as reflected in conventional linguistic expressions:

- ***Intensity is heat***: "There was ***heated*** political debate."; "The video ***fired up*** activists on both sides."
- ***Intensity is speed***: "The conversation had been ***sluggish***, but we are seeing a ***sudden leap.***"
- ***Intensity is strength (of physical effect)***: "Cheryl was ***hit hard*** by Carly's story."

Combining this idea with the idea of conceptual mapping, we get a novel perspective on the embodiment of social cognition. This perspective is based on the assumption that many bodily processes are similarly experienced by all or most people because of the types of bodies humans have and their manner of negotiating their surroundings. For example, most people feel warm during vigorous exercise; most people lie down when they feel ill; and most people avoid unpleasant smells and painfully hot surfaces. Through repeated experiences of these bodily processes, people acquire concepts that represent their phenomenal quality, time course, and correlates. These concepts have been called ***experiential gestalts*** (Lakoff & Johnson, 1980) and ***image schemata*** (Kövecses, 2005). For our current purposes, we can call them bodily concepts.

A bodily concept provides a mental scaffold to construct a metaphoric representation of an abstraction (Williams et al., 2009). To illustrate, the reader has likely spent a lifetime habitually approaching desired objects and pulling them toward the self, and likewise distancing the self or pushing undesirable objects. Based on these experiences, you learned a bodily concept of physical approach and avoidance. By means of metaphor, you can apply that concept as a

template to think and communicate about things that are not literally objects in space, such as motivation ("She's ***grabbing*** this opportunity."); relationship intimacy ("I feel like you're ***pushing me away.***"); international relations ("The U.S. is ***reaching out*** to China."); time ("Can you ***move*** our meeting ***closer***?"); and politics ("#MeToo met with ***pushback*** in Washington.").

Testing Bodily Metaphor's Influence on Social Outcomes

Do people really use their bodies to make sense of social concepts? They certainly talk as though they do: The world's languages are brimming with body-metaphoric expressions (Kövecses, 2005). Still, linguistic metaphors may be simply idioms (figures of speech) that tell us little about the way people ordinarily think (Gibbs, 2014). To get a closer look, social psychologists have developed empirical strategies that can be used to test a bodily metaphor's causal influence on social outcomes (for a more detailed review, see Landau, 2017).

The ***metaphoric transfer strategy*** is based on the reasoning that if people use a source to represent a target abstraction, then manipulating their experience of that source should transfer across the metaphor's mapping, leading them to process analogous elements of the target in ways that correspond to source knowledge. If, alternatively, metaphor does not inform cognition, there would be no reason to expect such effects because people's representations of the abstraction would not be systematically structured around the source.

Support for this reasoning comes from studies showing that manipulating people's sensations, movements, and proprioceptive states changes how they perceive, reason about, evaluate, and remember metaphorically-linked abstractions. Consider, for example, conventional linguistic metaphors linking social power with high vertical positions ("She's a ***rising*** star") and powerlessness with low vertical positions ("They're at the ***bottom*** of the hierarchy"). Going beyond language, researchers have shown that increasing the vertical, but not the horizontal, distance between pictorial representations of a manager and subordinates (7 cm vs. 2 cm) led participants to view the manager as more powerful (Giessner & Schubert, 2007; Lakens et al., 2011). Similar effects involve other bodily states and judgments of abstract social characteristics:

- Sensations of ambient warmth (vs. coldness) heighten feelings of social support (IJzerman & Semin, 2009).
- Hot backgrounds bias perceptions of facial anger (Wilkowski et al., 2009).
- Touching hard (versus soft) textures leads to stricter social judgments (Ackerman et al., 2010).
- Fishy smells increase doubts about others' trustworthiness (Lee & Schwarz, 2012).
- Sweet tastes increase others' perceived agreeableness (Meier et al., 2012).
- Priming spatial distance (by connecting dots on graph paper) decreases feelings of familial attachment (Williams & Bargh, 2008a).
- Inducing physical disgust leads to stronger moral judgments (Schnall et al., 2008).
- Holding a heavy versus light object (e.g., a 2.29 lb clipboard vs. a 1.45 lb clipboard) increases judgments of importance. This effect holds for judgments of community issues (Jostmann et al., 2009; Zestcott et al., 2017), a job applicant's seriousness (Ackerman et al., 2010), the severity of a disease (Kaspar, 2013), and a book's literary signi□icance (Chandler et al., 2012).

In connection with these effects, the metaphoric transfer strategy presupposes that the metaphor of interest is chronically accessible—always there, on the periphery of consciousness. That is why we expect that variations in source experience will automatically transfer over to produce analogous changes in target processing. There are likely to be other cases, though, where the situation determines whether a given metaphor is accessible.

In the latter cases, researchers can use the ***metaphoric framing strategy***: Expose some people to a metaphoric framing—a message that compares a target to a super□icially dissimilar source using words, images, or other modalities. Participants in comparison conditions receive an equivalent message framing the same target in literal terms or using an alternative metaphor. If exposure to a metaphoric framing activates a mapping, then it should lead people to interpret the target in ways that correspond to their source knowledge, even if they are not consciously aware of thinking by analogy to the source (Ottati et al., 2014).

In one illustrative study (Morris et al., 2007), participants read commentaries that compared trends in the stock market to either living agents (e.g., "This afternoon the NASDAQ starting ***climbing*** upward.") or inanimate objects (e.g., "This afternoon the NASDAQ was ***swept*** upward."; italics added). Next, participants were asked to predict what would happen to those trends the following day. People generally know that living agents, unlike inanimate objects, move with the intention of reaching destinations. Thus, we can predict that people exposed to an agent-metaphoric framing will transfer this knowledge and infer that the price trends will continue along their current trajectories. This is exactly what was found, suggesting that exposure to a metaphoric framing activated a metaphor that led recipients to interpret its target in ways that correspond to its bodily source.

Meta-Theoretical Distinctions

Conceptual Metaphor Theory shares common ground with several cross-disciplinary perspectives on embodiment, many of which are featured in this volume. Classical and contemporary philosophers propose that patterns in bodily functioning constrain the meanings people give to reality, including their basic notions of time, causation, morality, and personhood (Gibbs, 2006; Gill, 1991; Lakoff & Johnson, 1999; Prinz, 2004). Developmental psychologists observe that children use physical concepts to scaffold abstractions (Piaget, 1927/1969). Within social psychology, a number of theoretical frameworks, including the perceptual symbols systems model (Barsalou, 1999) and embodied grounding approach (Semin & Smith, 2008), claim that social concepts are connected to the brain's modal systems for perceiving and interacting with the physical environment. The burgeoning study of metaphor harmonizes with these (and other) embodiment perspectives and backs them up with experimental evidence.

Still, confining metaphor research to the embodiment camp obscures two meta-theoretical distinctions. Metaphor can have theoretically interesting and practically important consequences for social cognition that do not critically involve the body. Also, metaphor is only ***one channel*** through which body and mind can interact.

Disentangling it from other mechanisms will provide unique insight into ***how*** social cognition is embodied, and not just ***that*** it is embodied. Let us consider each distinction in turn.

Metaphors Vary in Embodiment

We have seen that some metaphors transfer bodily concepts. Digging deeper, however, we see that metaphor engages the body to varying degrees.

Online Bodily Metaphor. In some cases, metaphor operates as a chronically accessible mapping that recruits ***currently salient*** bodily states to guide target processing. This online transfer presumably underlies the documented effects of experimentally induced sensorimotor states on social perceptions and attitudes, examples of which were listed earlier. Online bodily transfer also guides judgments when a sensorimotor quality is a property of the stimulus rather than the perceiver. Consider Meier et al.'s (2004) examination of the metaphoric link between positive/negative affect and brightness/darkness (e.g., "These are ***dark*** days, but the future is ***bright***"). They randomly paired positive affect words (e.g., hero) and negative words (e.g., liar) with light or dark font colors and asked participants to evaluate them as quickly as possible. Despite the irrelevance of the font color manipulation, positive (negative) affect words were evaluated more quickly when assigned to the brighter (darker) color.

Offline Bodily Metaphor. We have seen that, for Conceptual Metaphor Theory, metaphor use supports target understanding by borrowing a source as a template. A corollary is that some metaphors can transfer a bodily concept even when people are ***not concurrently experiencing a relevant bodily state***.

To illustrate, imagine that Jason conceives of civil rights (the target) metaphorically as a physical journey. He borrows some (but not all) elements of his journey concept and maps them onto analogous elements of civil rights (as depicted in Fig. 20.1). This enables him to represent civil rights activism as having a ***starting point*** in predecessors' pioneering efforts and to view an egalitarian society as a ***destination***. He can also evaluate historical events as creating ***obstacles*** or ***moving*** society ***forward***. Critically, Jason can perform this mental

mapping while plopped into his La-Z-Boy recliner—more precisely, without concurrently experiencing a bodily state stereotypically associated with journeys.

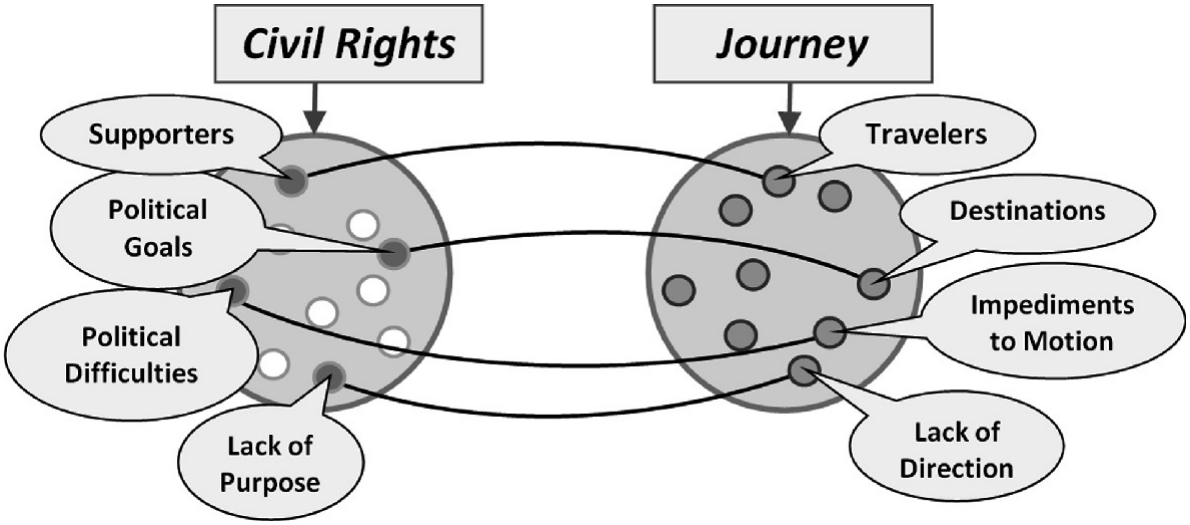


Fig. 20.1 Depiction of a portion of the concpetual mapping created by the metaphor ***civil rights is a journey***

To test this possibility, we (Landau et al., 2014) asked college freshmen to imagine themselves in the future as an academically accomplished graduate. Some students were led to visualize that possible identity metaphorically as a destination on a journey representing their college career, while others reflected on that identity in literal terms. We reasoned that the journey-metaphoric framing would prompt students to draw on their familiar knowledge of journeys, even if they are not consciously aware of doing so. One thing people know about journeys is that the path in front of them designates an ordered sequence of steps that they must take to move from "here" (current location) to "there" (destination). Supporting predictions, the journey-primed students felt more confident that their current academic activities fit into a sequence of actions necessary to attain their possible identity and thus saw a stronger connection between their current and future academic identities. Because study participants completed all materials while seated in a small cubicle, it is unlikely that the observed effect drew on salient bodily states. Instead, exposure to a metaphoric framing presumably called up a conceptual template learned from repeated experiences with goal-

directed motion along a path to represent the relation between abstract personal identities.

Other examples of offline metaphors come from the dozens of studies using the metaphoric framing strategy discussed earlier. Recall that, in those studies, metaphor activation is manipulated by means of exposure to a metaphoric message, not an induced bodily state. For example, Morris et al. (2007) showed that incidental exposure to agent-metaphoric phrases (e.g., "climb") led participants to transfer a physical concept (agents move with the intention of reaching destinations) to make analogous inferences about an abstraction (stock market trends will continue along their current trajectory).

These and other findings suggest that metaphor use enables people to borrow body-related knowledge to grasp ideas that are otherwise vague or complex, regardless of what is happening in or around their bodies at the moment. Indeed, our guiding analysis yields a more provocative (though untested) possibility: A metaphor can transfer a bodily concept even among people who have ***never*** experienced a characteristic sensorimotor expression of that concept. For example, people may be led to conceptualize an overwhelming workload in terms of drowning even if they have no first-person experiences with drowning.

Non-Bodily Metaphor. Many socially relevant metaphors do not seem to arise out of bodily concepts. Rather, they derive their content and structure from schematic knowledge of other types of things. Personification is a prime example. Everywhere people communicate about intangible things as though they were human-like agents. Political leaders cast unemployment, apathy, and inflation as enemies against which to collectively struggle; some groups enact rituals that attribute health maladies to the scheming of ancestral spirits (Turner, 1995); and origin myths—stories about how the world was created—explain cosmological events in terms of the familiar ways that people fall in love, procreate, express emotions, and so forth (Stookey, 2004). This metaphor is as good a candidate as any for universal status, but it is rooted not as much in the types of bodies humans have as in their folk psychology—their common fund of knowledge about mental states (intentions, goals, beliefs) and how those states link to action. (Of course, this and other sources are "embodied" in the sense that they

are instantiated in the nervous system, but that is not what makes them useful for thinking). A few other examples of widespread but not-particularly-bodily metaphors:

- Many groups represent (e.g., in iconography) the fate of nations and the outcome of political events (e.g., military campaigns) in terms of ***fertility*** and regeneration (Stookey, 2004). This metaphor arises from common conceptions of ***life***—where it comes from, what sustains it—rather than representations of sensorimotor experiences.
- From classic Confucianism right up to modern political rhetoric, conceptions of national identity are couched in terms of parent-child relations and filial piety (Lakoff, 1996; McAdams et al., 2008). The source here is ***family bonds—***knowledge that is shared across cultures (Pepitone & Triandis, 1987).
- Many sources represent schemas for cultural products and institutions. For example, the concept ***building*** is a common source in English, German, French, and Russian (Chilton, 1996). People co-opt ideas like ***foundation***, ***rooms***, ***collapse***, and ***rebuild*** to think about theories, relationships, careers, social movements, the cosmos, and a great deal else. Although people obviously have bodily experiences with buildings, this metaphor leverages stereotyped knowledge of how buildings work. Other common metaphors sourced in cultural products include ***the mind is a computer*** ("I don't have enough ***bandwidth*** for you today."), ***time is money*** ("You didn't ***budget*** your time well."), and ***life is a story*** ("This relationship is a new ***chapter*** for me.").
- Many metaphors are sourced in event scripts prescribing how various cultural activities customarily unfold in time. A person who has never had direct sensorimotor experiences with military combat, organized sports, or theatrical productions could nevertheless conceive of an argument as war ("I cannot ***penetrate*** her ***defenses.***"), sex as a sport ("Did you ***score*** last night?"), and socializing as a stage play ("Just put on your ***mask*** and stick to the ***script***.").

I stress the significance of non-bodily metaphors because they have important consequences for practical outcomes such as moral judgments, political attitudes, compliance with health

recommendations, and relationship satisfaction (Landau, 2017). We miss these consequences by assuming that all metaphors are rooted in the body. As an illustration, consider a widespread metaphor comparing the federal budget to a household budget. You hear it, for example, in campaign attack ads that say, "We balance our budget at home; why won't so-and-so in Washington do the same?" The implication is that, just as families have to live within their means, the government must do the same by cutting back on spending for federal programs (an implication that contrasts with the recommendations of many influential economists who urge stimulus spending: Krugman, 2012).

Even incidental exposure to this "household" metaphor biases policy decisions. In one study (Landau et al., 2017), participants read a (fabricated) article arguing in favor of cuts to the federal budget. In one condition, the article included phrases and visual cues to suggest that the federal budget operates in essentially the same way as a household budget. In another condition, those messages were replaced with equivalent literal messages. Afterwards, participants were asked how much the government should cut spending for federal agencies like the Departments of Education and Health and Human Services. Participants primed with the "household" metaphor were especially likely to transfer their knowledge that, in a well-operating household, families must reduce spending to live within their means, and therefore to advocate for funding cuts to federal programs. Findings like these show that metaphor can bias cognition about important matters without engaging the body.

Embodied Influences Vary in Metaphoricity

Just as metaphor engages the body to varying degrees, embodied influences on social cognition vary in their metaphoricity. To unpack this point, it helps to boil down a conceptual metaphor to two components. Metaphor is a relationship between mental entities that are ***superficially dissimilar*** (sharing few if any surface-level features) and ***structurally similar*** (sharing a pattern of relations between analogous elements).

Thus, at the low end of the metaphoricity spectrum lie embodied influences between superficially ***similar*** entities. A good example is

simulation. According to Barsalou's (1999) perceptual symbols systems model, concepts contain representations of bodily states that customarily occur during interactions with relevant stimuli and contexts. These inputs are not translated into abstract symbols but are recorded by systems of neurons in sensorimotor regions of the brain. Thinking about concepts involves the ***simulation***, or neural reactivation, of associated bodily states. For example, when Chris thinks back to bowling as a child, he simulates tactile representations of a bowling ball's smooth surface and proprioceptive representations of adjusting his balance to hurl a ball down the alley.

Like metaphor, simulation is a mechanism through which bodily states can inform social concepts, even when the individual is not currently interacting with relevant stimuli. But unlike metaphor, simulation involves bodily states that are similar to their respective concepts. Bodily states are represented as part of the concept they refer to, and they were encoded in long-term memory through sensorimotor experiences with category members corresponding to that concept. Returning to our example, Chris's bowling concept contains modality-specific representations ***about*** bowling.

Another way to understand superficial dissimilarity is that, in a bodily metaphor, the source is a concept in its own right that ***can*** scaffold a target but can also stand on its own. For example, you have an elaborate bodily concept of physical cleanliness that encompasses experiences with disgust and dirt avoidance. By means of metaphor, you can apply that concept to conceive of ideas in different domains, such as morality ("***Scrub*** the Internet of ***filth***"), but otherwise it plays an independent role in your mental life. Another example: You can think and talk about friendliness in terms of physical warmth (IJzerman & Semin, 2009; Williams & Bargh, 2008b), but you can also think about warmth in ways that are irrelevant to friendliness (e.g., warming up the car on a winter morning). Indeed, this separability of source and target is what allows people to disagree about which is the most apt source for comparison to a given target. For example, in the 1990s, politicians debated whether the Persian Gulf War (Operation Desert Shield/Storm) was best understood as a ***nightmare***, a ***chess game***, an ***unpredictable tiger ride***, the ***Super Bowl***, or an ***Easter-egg hunt*** (Lakoff, 1992; Pancake, 1993; Sandikcioglu, 2000; Voss et al., 1992). We do not

see this separability in the case of other embodied influences because bodily states and processes occur during interactions with concept-relevant contexts.

Toward the middle of the metaphoricity spectrum lie effects involving bodily states and social outcomes that are dissimilar on the surface but that do not share a similar structure. In these cases, people do not seem to transfer the "logic" of a bodily state or process—their conception of what it is, how it feels, and how it works—to understand and relate to a target.

Take the case of self-perception effects. Wells and Petty (1980) had college students listen to an audio recording that included an editorial advocating tuition increases at their school. Under the guise of testing the durability of the headphones, they asked participants to move their chins up and down or from side to side while listening to the recording. Afterward, participants were asked how much they thought tuition should be. Those who had been nodding their heads the entire time were in favor of tuition fees that were about 38% higher than those who had been shaking their heads.

Like metaphor-mediated effects, here we see a motor movement influencing attitudes toward a superficially unrelated topic. Tuition pricing is a complicated socioeconomic issue that looks nothing like lifting one's chin up and dropping it down repeatedly. However, the relation between the motor movement and the attitude object is not likely to be one of mapping between analogous elements. Participants in this study were not ***understanding*** tuition—what it is, why it changes—using their knowledge of head nodding. A more plausible interpretation is that people usually engage the muscles in their head and neck in this way when they are signaling their agreement with something. Thus, people unconsciously use this same sequence of muscular movements to infer agreement.

Effect Categorization

The meta-theoretical distinctions just outlined give rise to a series of questions (summarized in Table 20.1) that help researchers determine whether a body-related effect is mediated by metaphor or another mechanism. This categorization scheme is intended only as a small

piece of what might one day be a comprehensive taxonomy of embodied influences on social cognition.

Table 20.1 A piece of a taxonomy of embodied influences on social cognition

For a given effect of a bodily state/process (e.g., sensation, motor routine, salient bodily concept) on a social outcome, consider these questions…
Question 1: Is the bodily state/process ***superficially dissimilar/irrelevant*** to the outcome?
"No, they are related." The effect is not mediated by metaphor. It may be due to
• Embodied simulation (Barsalou, 1999)
• Somatic marker (Damasio, 2001)
• Priming effects on overt behavior (Bargh et al., 1996)
"Yes, the two variables are superficially irrelevant." Proceed to Question 2
Question 2: Is the bodily state/process ***structurally similar*** to the outcome? Do they share at least one relation between analogous elements?
"No, they don't seem to share a structure." The effect is not mediated by metaphor. It may be due to
• Misattribution of arousal (Kay et al., 2010; Zanna & Cooper, 1974)
• Self-perception (Strack et al., 1988; Wells & Petty, 1980)
• Feelings/moods as information (Forgas, 1995; Schwarz & Clore, 2003)
• Arousal/wakefulness (Bodenhausen, 1990)
• Bodily motives (Nelson & Morrison, 2005)
"Yes, they share structure." Proceed to Question 3
Question 3: To what degree is the body engaged?
"A sensorimotor state was salient (e.g., experimentally induced) at the same time that the outcome was observed." The effect is probably due to
• Online bodily metaphor (Meier et al., 2004)
"Although a sensorimotor state and the outcome did not co-occur, people seem to have drawn on commonplace knowledge of a bodily state/process." It's probably
• Offline bodily metaphor (Morris et al., 2007)
"Oops, I guess people weren't drawing on a bodily concept; they seem to have drawn on commonplace knowledge of a product, institution, or activity." That's okay; it's probably
• Non-bodily metaphor (Landau et al., 2017)

First, we ask whether the effect's bodily state/process (e.g., sensorimotor experience, semantic prime) is superficially relevant to the outcome. Is it part of how people normally experience the outcome,

or do the two variables refer to different classes of things that people relate to in different ways? If they are superficially relevant, then the effect is not mediated by metaphor.

Consider evidence that when participants made judgments about words related to emotion concepts, they exhibited facial muscle activity specifically associated with those emotions (e.g., corrugator supercilii muscles used in disgust expressions: Niedenthal et al., 2005). This finding suggests that facial muscles that are customarily activated in response to emotion-eliciting stimuli constitute a portion of the content of respective emotion concepts. The bodily states are directly relevant to the processing of emotion concepts. This is an example of simulation, not metaphor.

As another illustration, consider evidence that people experience physiological reactions (e.g., vasoconstriction) while observing people lying, and that by attending to those bodily signals they can better discern liars from truth-tellers (Brinke et al., 2019). These physiological reactions have direct relevance to the outcome of lie detection—they signal sympathetic arousal in response to being deceived—and thus do not influence that outcome by means of metaphor. This finding is best understood as support for the somatic marker hypothesis (Damasio, 2001), which states that there are somatic changes that become automatically associated with certain contexts. When people encounter those contexts again, those reactivated bodily states, experienced as emotions, serve as a marker or cue for what will happen next, helping to shape their decisions.

What if the effect's bodily state/process ***is*** superficially unrelated to the outcome? We proceed to Question 2: Do these variables share a similar structure? Structural similarity is less intuitive than superficial similarity, so it will help to rephrase this question in a couple ways: Is there reason to believe that people are using the bodily state/process as a conceptual template for representing analogous elements of a target? Or, more precisely: Do the bodily source and target share at least one ***relation***, such that two elements within the source relate in a way that corresponds to two elements within the target? To see what I mean, look back at Fig. 20.1's depiction of a metaphor's mapping. You see four connecting lines, each representing a correspondence between analogous elements of source and target. A shared structure is

when two elements ***within*** the source relate in a way that corresponds to the relation between two elements ***within*** the target, creating at least two correspondences. For example:

Relation = Energizing and coordinating collective action: A locatable destination ŌŖ ŗŒ travelers on a journey ńŖ an egalitarian society ŌŖ ŗŒ civil rights activists.

With this in mind, we can see that several body-related effects are not mediated by metaphor. We have already mentioned the example of self-perception effects, such as facial feedback effects on attitudes (Strack et al., 1988). The theoretical explanation of these effects is that people often lack insight into how they feel about something, so they look to their own behaviors to make inferences. Because they are accustomed to expressing their attitudes though motor movements, they interpret those movements as cues to their feelings. The bodily process serves as a signal, not a conceptual framework for understanding the attitude.

Or consider evidence that social judgments are affected by circadian rhythms, the individual differences in daily cycles of mental alertness. In one study (Bodenhausen, 1990), some participants were asked to play the roles of jurors in a case where the offense was stereotypical of the defendant's group. Did participants allow their stereotypes of the defendant to sway their verdicts? Not if they were participating in the study during their optimal time of day. But if morning people were participating in the evening or night owls were participating early in the morning, their verdicts were strongly colored by stereotypes. On the surface, the body's cycles of mental alertness look nothing like one's ability to set aside biases and make fair judgments. Still, this is not a metaphor-mediated effect because it is unlikely that participants were judging the defendant using what they know about alertness.

Imagine that the body-related effect under consideration involves a bodily state/process and a social outcome that we have deemed to be superficially dissimilar (Question 1) and structurally similar (Question 2). I believe it is helpful to categorize that effect as mediated by metaphor as distinct from other mechanisms identified in the embodiment literature. Still, we can gain additional taxonomic precision by addressing Question 3: To what degree is the body

engaged? As seen in Table 20.1, I expect answers to this question to cluster around the metaphor types defined in a previous section: online bodily metaphor; offline bodily metaphor; and non-bodily metaphor. That said, this categorization scheme is a mere starting point. Researchers interested in fleshing out a complete taxonomy should identify additional quantitative and qualitative distinctions in bodily engagement.

Hypothesis Generation

We have seen how the current meta-theoretical distinctions guide categorization of prior findings. They are also useful as a basis for generating novel hypotheses regarding the effects of activating a bodily metaphor as distinct from other mechanisms. For example, by distinguishing online from offline-bodily metaphors, we can hypothesize that people will apply salient bodily concepts to process a target even if they are not concurrently experiencing relevant sensorimotor states.

To further illustrate the generative potential of the current analysis, in this section I summarize hypotheses that uniquely follow from Conceptual Metaphor Theory's claim that activating a bodily metaphor prompts people to map a target onto a superficially dissimilar bodily concept. Put differently, these hypotheses ***do not*** follow from theoretical perspectives that treat embodiment as a monolithic construct or that posit bodily mechanisms other than the systematic conceptual mapping characteristic of metaphor (and a few closely related mechanisms such as analogy and conceptual blends: Fauconnier & Turner, 2002; Holyoak & Thagard, 1994).

Alternate Sources

We have already seen that a metaphor's target and source are not in an exclusive relationship. Instead, metaphor can provisionally borrow a source that otherwise stands on its own. This suggests that experimentally manipulating which sources (bodily or non) people use to understand a given target will highlight and downplay different sets of target elements and, in this way, change their target judgments in source-specific directions.

In one illustrative study, Thibodeau and Boroditsky (2011) asked participants to read a report about the crime rate in the (fictitious) city of Addison. For some participants, the crime problem was framed as a "beast preying" on Addison; for others, it was a "virus infecting" Addison. Both groups then read identical crime statistics before being asked to propose a solution to Addison's crime problem. The "beast" metaphor led participants to generate solutions based on increased enforcement (e.g., calling in the National Guard). In contrast, the "virus" metaphor led participants to generate solutions that were diagnostic and reform-oriented (e.g., finding the root cause of the crime wave). When asked what influenced their thinking, participants tended to mention the crime statistics, but the results clearly show that they generated solutions that were consistent with their source knowledge: If crime is a beast, it must be "fought;" if it is a disease, it must be "treated."

Source Resonance

If metaphor creates a systematic mapping, then it should transfer ***personalized*** knowledge about the metaphor's source to interpret its target. Thus, an activated metaphor should affect target processing differently depending on individuals' pre-existing source knowledge. In one demonstration of this ***source resonance*** hypothesis, Landau et al. (2018) exposed some participants to phrases and imagery comparing ultraviolet (UV) radiation to a personified sun intent on physically assaulting them. Those with a strong pre-existing fear of violent altercation responded with increased worry about skin cancer risk and strengthened intentions to use sun protection (Fig. 20.2). Those lower in violence fear showed the opposite effect, responding to the assault metaphor with lower levels of worry and protection intentions. When the message framed the same facts about UV exposure in a literal manner, individual differences in fear of violence did not predict these outcomes.

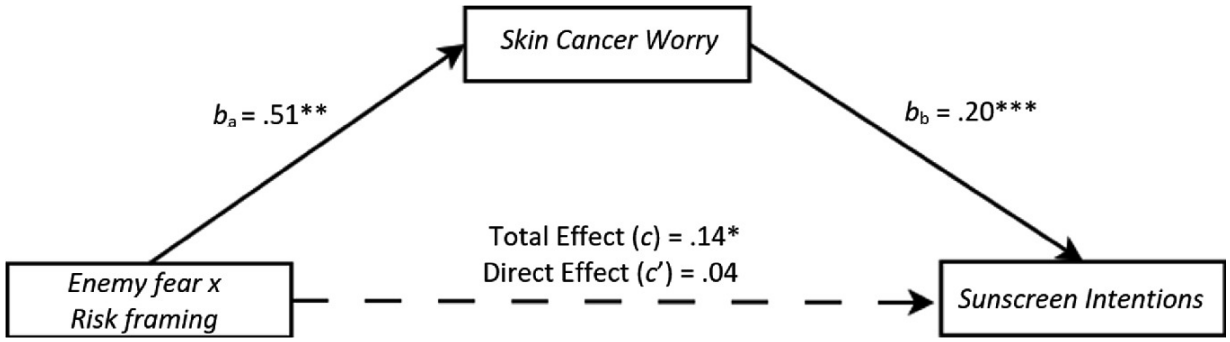


Fig. 20.2 Testing a source resonance hypothesis: Framing UV exposure metaphorically as physical assault increased skin cancer worry and protection intentions only among those with a high pre-existing fear of violent altercations
(data from Landau et al., 2018; Study 1)

Metaphoric Fit

The ***metaphoric fit*** hypothesis models the interaction between the framing of an elusive problem and the framing of a candidate solution. For example, a metaphoric message that frames a health risk in terms of a dissimilar hazard will be more persuasive if it also frames the recommended prevention behavior as metaphorically addressing that hazard (vs. in literal terms or using another metaphor), even though this metaphoric "fit" is irrelevant in a literal sense. In one study (Keefer et al., 2014), when an article framed depression metaphorically as a problem of being physically down (vs. literally as chronic negative mood), an anti-depressant medication framed metaphorically as elevating—as ***lifting*** one ***up***—was seen as effective, whereas the same anti-depressant framed with another metaphor—as ***brightening*** one's ***dark*** mood—was seen as a dud. Findings like these suggest that an activated bodily metaphor leads people to rely on the "logic" of a bodily source to reason through a problem and its candidate solutions (e.g., "If I'm feeling ***down***, then an effective drug needs to lift me ***up***").

Construal Mindset

Imagine that Carly sees a brochure at the pharmacy that likens unprotected sex to reckless driving. Will she respond to this message by recruiting her bodily concept of vehicle operation to interpret the severity of risks involved in unprotected sex and the efficacy of recommended prevention behaviors? Useful here is Conceptual Metaphor Theory's claim that using a metaphor to understand a target

in terms of a source requires looking past those concepts' superficial differences to encode their shared structure or relations among their parts (Holyoak & Thagard, 1994; Lakoff & Johnson, 1980). In this example, sex and vehicle operation have different surface attributes (e.g., sex rarely involves signal lights or tollbooths). Thus, to understand sex using this metaphor, Carly needs to look beyond the concepts' distinctive details and appreciate their shared relations: Both activities are exciting but can result in harm unless proper precautions are taken.

Thus, we can hypothesize that when people are in a general mindset that is focused on ideas' structure, but not a mindset focused on details, they will be more likely to appreciate how a bodily source provides a useful template for understanding a target and will therefore process the target in ways that correspond with their source knowledge. One supporting study (Landau et al., 2019) showed that, among participants primed with a mindset oriented toward structure, framing UV exposure metaphorically as physical assault (vs. literally as a major health threat) increased concern about skin cancer risk (Fig. 20.3). When participants were instead primed with a construal mindset focused on details, the assault-metaphoric framing had no effect on perceived cancer risk. A parallel pattern emerged for intentions to wear sunscreen. Participants primed to look at the forest responded to an assault metaphor with stronger intentions to protect their skin when going outside, whereas those zoomed in on the trees were unaffected. These and similar results (Jia & Smith, 2013) suggest that people do not automatically assimilate a provided metaphor into their online cognition, and Conceptual Metaphor Theory tells us that construal mindset will moderate metaphor adoption.

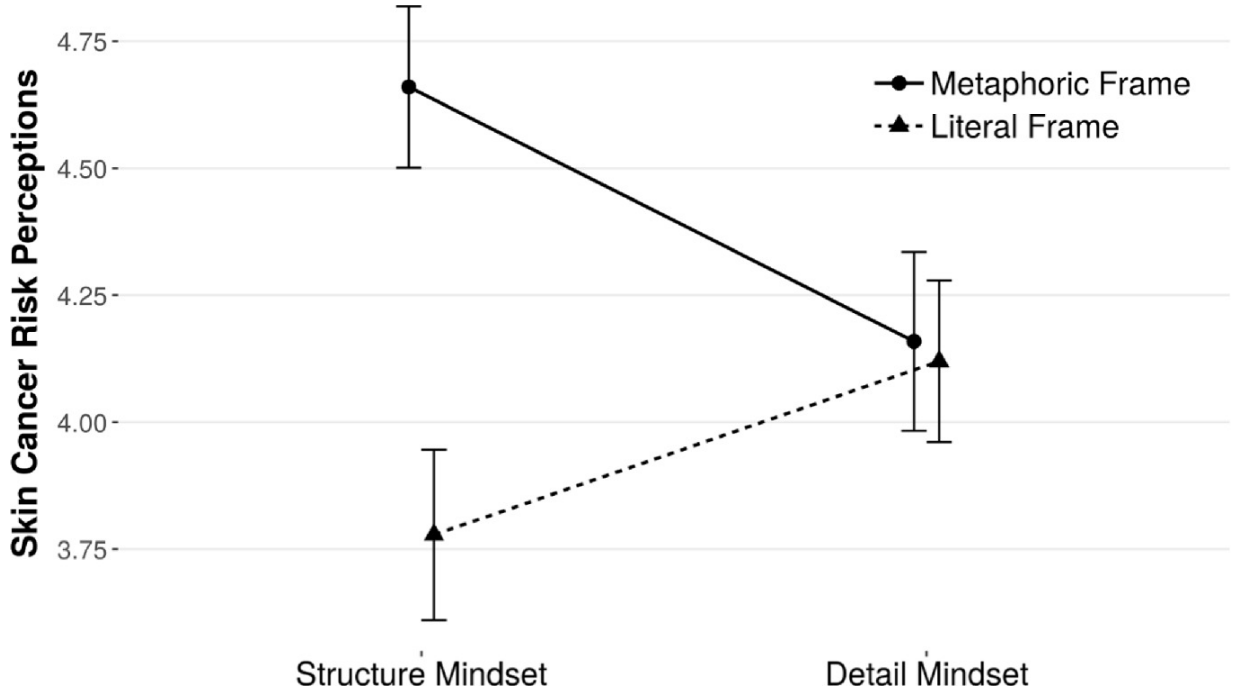


Fig. 20.3 A bodily metaphor (***UV risk is physical assault***) influenced target perceptions among participants primed to appreciate the source and target's shared structure, but not among those primed to focus on distinctive details

(data from Landau et al., 2019; error bars represent standard errors around group means)

Certainty Motivation

According to Conceptual Metaphor Theory, metaphors do not just sit there; they help people feel as though they have a handle on abstract ideas (Lakoff & Johnson, 1980). Other lines of research show that the motive to feel certain varies across situations (Kruglanski, 2004). Combining these ideas, we can hypothesize that people will rely on metaphor to make judgments particularly when they are motivated to reduce unpleasant feelings of uncertainty.

In one study testing this possibility (Keefer et al., 2011), college freshmen were asked to write about one of three topics: uncertainties about the value of their college experience, a recent bout of intense physical pain (an aversive topic for comparison with uncertainty), or a neutral topic. Students were then asked to think back to their decision to attend their current university rather than another college or university. They were handed a worksheet with six vertically arranged lines and asked to list the factors behind that decision in either an upward direction (from bottom line to top line) or a downward

orientation, depending on condition. Finally, they were asked how satisfied they were with their decision.

As shown in Fig. 20.4, arranging decision factors on a vertical axis influenced decision satisfaction in line with the metaphors ***up is good*** and ***bad is down***, but only when uncertainties about college were salient. Students made unsure about college's value judged an up-framed (down-framed) decision as more (less) satisfying. Also of importance, students who were not made to feel uncertain about college's value did not rely on verticality cues to inform their attitudes.

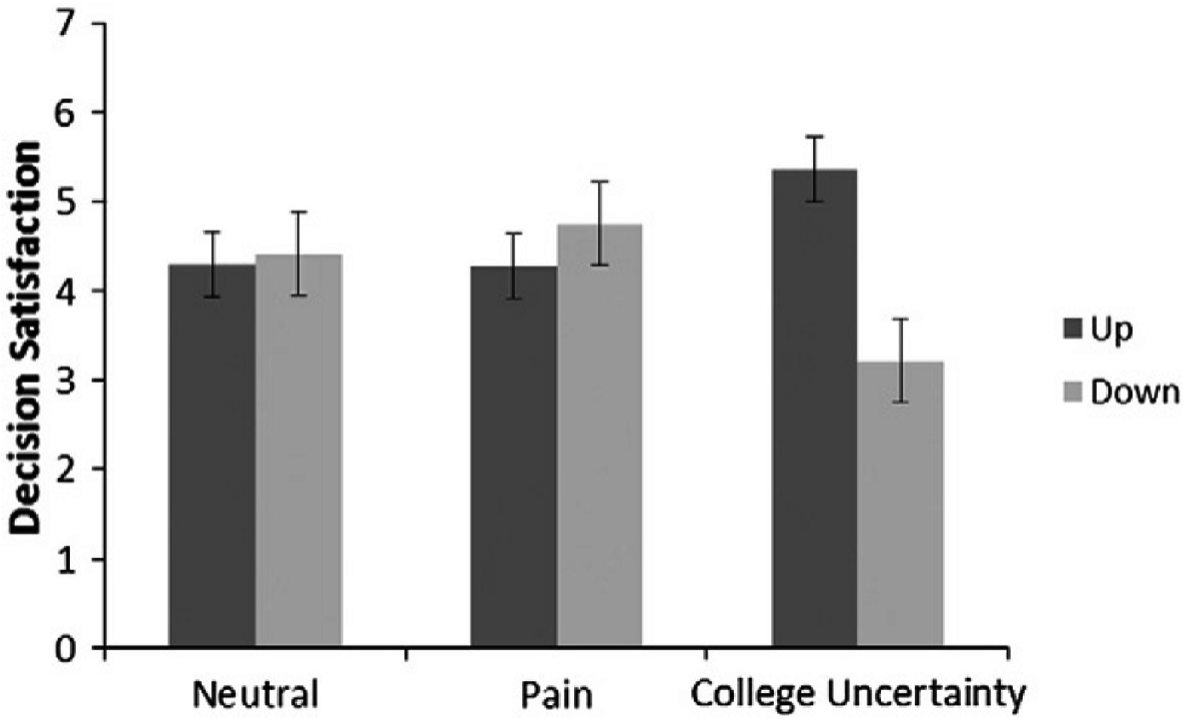


Fig. 20.4 Metaphors of ***up*** and ***down*** affected satisfaction with one's university decision only when uncertainties about college were salient (data from Keefer et al., 2011; error bars represent standard errors)

The research summarized in this section is intended to illustrate that drawing clearer definitional boundaries around mechanisms of embodied (social) cognition enables researchers to generate novel hypotheses. We specified that metaphor is a conceptual mapping that people can lean on to lend structure to otherwise elusive ideas. This definition gives rise to the four hypotheses examined in this section. The embodiment literature would benefit from a similar investigation of other mechanisms.

Conceptual Re nement

Where have we come? Visualize the embodiment literature metaphorically as a vast warehouse where theorists and researchers have for centuries dropped off theories, concepts, and empirical ndings. Today we gaze out over these huge piles of stuff and, with a self-assured smile, declare the demise of the ontological division between mind and body that stretches back to antiquity.

But repeatedly pointing to the ***sheer quantity*** of stuff, it seems to me, is to beat a dead horse, because no self-respecting researcher doubts that mind and body are in constant dialogue. The time is ripe to ***organize*** this sprawling collection. We need to drag items to the curb, inventory them, and return them to clearly labeled containers where they can be put to good use. To that end, I proposed meta-theoretical distinctions that can be used to determine which ndings do and do not go in the "Metaphor" container.

One problem: My analysis is not only incomplete, but it is facile. For simplicity's sake, I chose to back up my points with straightforward examples, but a closer look reveals clouds of ambiguity. Fortunately, probing the gray areas brings into focus new conceptual issues for future work.

Fifty Shades of Dissimilarity

To determine whether a bodily state / process and a social outcome are in a metaphoric relation (as variously expressed in language, thought, or behavior), we asked whether, on the surface, they refer to similar or different categories of things. For the examples I provided, the answers are intuitive (e.g., exing the zygomaticus major muscles into a smile is similar to happiness; verticality and brightness are not). But of course, similarity is a continuous, not a dichotomous, variable, and researchers do not yet agree on where along that continuum to mark the metaphor cutoff. Consider these statements:

a. "The Iraq War was a ***circus***"

b. "The Iraq War was ***Vietnam***."

The concepts compared in (a) are quite dissimilar. The Iraq War did not feature clowns or tight-rope walkers. This is a metaphor for sure. But what about the comparison in (b)? The statement ***is*** false in a strict literal sense: The Iraq War did not take place in Southeast Asia between 1954–1975. But is this a metaphor or a mapping between two exemplars of the ***same*** category, namely, military conflict (where, e.g., George W. Bush corresponds to Richard Nixon)? I do not know.

The picture gets even murkier if we consider the widely accepted origin story of metaphors. In a nutshell, the story is that developmentally early correlations between social experiences and interactions with the physical environment form the basis for metaphoric conceptions of those experiences later in development (Johnson, 1987; Lakoff & Johnson, 1999). To illustrate, most of us learned in childhood to correlate the loving embrace of parents or caregivers with a feeling of bodily warmth and, conversely, to associate distance from caregivers with decreased bodily warmth. At some point in cognitive development, this literal association acquired a secondary, figurative meaning. It became partially detached from direct sensory experiences, which enabled us to represent as warm/cold things that have no temperature (e.g., "I got a ***warm*** reception at NDSU").

An intriguing account, but two problems arise: First, this account implies that a metaphor's bodily source and social target were, at some developmental stage, ***not dissimilar at all***. They were tightly linked in experience. Second, exactly how (and when) they took on a secondary, figurative relation remains a mystery.

Active Mappings or Isolated Associations?

Like superficial similarity, structural similarity is a continuous variable. In some cases, a bodily concept and a social outcome share a rich mapping entailing several shared relations (Lakoff & Johnson, 1980, call these ***structural metaphors***). The "journey" metaphor is the textbook example.

But some metaphors have skimpier mappings, and it is worth asking whether they are metaphors at all. Consider metaphors that orient abstract ideas along a spatial (usually vertical) dimension (Lakoff & Johnson call these ***orientational metaphors***). These metaphors barely meet the structural similarity criterion: The relation

between up and down within the spatial domain is shared (via two correspondences) with the relation between (say) happy and sad within the affective domain. That implies that when Trevor says, “I’m feeling ***down*** today,” he is actively drawing on a spatial representation of down ***and*** up in polar relation. Perhaps he is, but perhaps he simply thinks ŖńŇ = ŇŒŚ ő. That is an isolated association, not a shared relation.

This issue urges us to reconsider some well-known ffindings. In one now famous study by Williams and Bargh (2008b), participants who briefly held a warm (vs. cold) coffee cup subsequently perceived a person as interpersonally “warmer”—that is, as friendlier and more trustworthy. This effect is often interpreted as evidence of online bodily metaphor, whereby a salient sensorimotor state is transferred automatically to evaluate an abstract personality characteristic. If that is true, and my mapping criterion is sound, then the momentary warmth sensation projected this mapping:

Warm ŌŖ ŗŒ cold ńŖ friendly ŌŖ ŗŒ unfriendly.

An alternative interpretation builds on the hundreds of studies showing priming effects on social perception. We would not be surprised if subtly exposing English speakers to the word “warm” led them to perceive someone as friendlier. But “warm” is a polysemous word and is likely stored in memory with literal meanings (temperature) and metaphoric meanings (temperament; Eddington & Tokowicz, 2015). It is plausible, then, that touching a warm cup primes “warm” in essentially the same way as a word presentation, activating both literal and metaphoric meanings (an alternative possibility also discussed by Holyoak & Stamenković, 2018). That alternative mechanism would look something like:

☕ → ***Warm*** → “This person seems friendly”.

This line of questioning raises the broader issue of “dead” metaphors that has preoccupied theorists for years (e.g., Bowdle & Gentner, 2005; Gibbs, 2014; Goatly, 2011). The controversy surrounds researchers’ reliance on ordinary language for clues to metaphor’s cognitive signifficance. They observe a conventional metaphoric expression and then attempt to peer under language’s hood to determine whether it reflects a conceptual metaphor or is a mere ffigure of speech—a “dead” metaphor. Linguists peer by analyzing

whether several expressions form clusters both within and across languages (Kövecses, 2005; Lakoff & Johnson, 1980); cognitive psychologists measure the time it takes to comprehend metaphor-related words and sentences (Glucksberg & Keysar, 1990); and social psychologists use the methods described in this chapter. Taken together, these inquiries dispel the notion that ***all*** metaphoric language is "just" language. But for any metaphor, the question is hard to settle.

Imagine that Rachel, while quarreling with her dad, yells, "I can't get this across to you!" It is possible that she found it difficult to conceptualize in literal terms the process of sharing her thoughts, so she leaned on the so-called conduit metaphor (Reddy, 1993) that portrays thoughts in bodily terms as objects shooting out of a speaker's head and landing in the listener's head (unless that listener is dad, of course). But it is also possible that she simply reached for a cliché as a handy means of expressing herself without borrowing images of objects bouncing between containers. Even if the phrase "get this across" had been motivated by an active mapping when it was first coined, it may have since "hardened" into an isolated linguistic nugget. Researchers should develop more precise means to empirically distinguish active mappings from such one-off associations (a useful starting point is Holyoak & Stamenković, 2018).

Mixed Bodily Signals

At any given moment, perceivers are experiencing, or have recently experienced, several sensorimotor states at varying levels of consciousness. The studies I reviewed show that metaphor can mediate between those states and social cognition, but it is unlikely that this channel is so undiscriminating that any and all bodily states are assimilated in this way. Imagine that we asked people to sit on a wobbly chair in a cold room and make judgments about a group presented on a bright screen. Would we expect them to perceive that group as "unstable," "cold-hearted," and "bright" all at the same time? A challenge for future research is to discover the conditions under which a bodily state serves as the input to a metaphor versus when, to paraphrase Freud, a bodily state is just a bodily state.

Complicating matters, the same sensorimotor state can mean different things. An illustrative study by Tamir et al. (2004) showed

that the meaning of a given muscle movement changes depending on the context in which it occurs. Participants were led to shake their heads side to side while watching a video (as opposed to nodding their heads)—a movement generally associated with disapproval. If, at the same time, they watched a video of a murderer, head shaking led to more negative judgments of the person, as we might expect. However, if they watched a video of a drug addict who had faced difficult circumstances, the participants inferred from their head shaking that they disapproved of the hardships she had faced, leading them to judge her more positively than the nodding participants. These findings show that the same movement can take on several, contextually sensitive meanings, and our minds flexibly integrate those meanings when forming judgments. But that insight has not been integrated into studies of online metaphoric transfer.

Also, what happens when people become consciously aware that they might be thinking with their bodies? Will they still use the body as a source of information? Research by Zestcott et al. (2017) suggests that people prefer to see themselves as thinking in a rational manner and thus ignore and even over-correct for passing bodily states. When participants completed a survey about the importance of improving the city's roads, those who completed the survey on a heavy clipboard (2.29 lb) judged the issue as more important than did students who held a light clipboard (1.45 lb). But if the experimenter told participants "just to let you know, some people have found the weight of the clipboard to feel heavy," the effect of weight on ratings of importance disappeared. People may use their bodies to think about abstract ideas, but not if something in the context makes them aware that they are doing so.

Tackling these and other conceptual issues will help researchers to map out exactly how the body shapes the social mind.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_21

21. Embodied Perspectives on Personality

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Abstract
Most theories of embodiment emphasize processes that are thought to be normative in nature. However, a consideration of the relevant processes (e.g., perception, awareness of afferent inputs, simulation abilities, metaphor usage) suggests that substantial individual differences could constitute the rule rather than the exception. The present chapter focuses on such sources of variability and does so in relation to four themes or lines of enquiry—how bodily factors shape personality, whether embodiment processes link personality to perception, how normative tendencies toward metaphoric thinking could give rise to variance across individuals, and how embodiment itself could be an individual difference. Although the reviewed literatures tend to be somewhat isolated from each other, juxtaposing them highlights many points of convergence. Ideas about embodiment could therefore contribute to new, process-oriented views of personality. In addition, individual differences can be leveraged to

show that embodied representational processes matter with respect to everyday functioning.

Keywords Embodiment – Personality – Individual differences – Conceptual metaphor

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The concept of embodiment cannot be summarized in any one particular way, in part because the concept emerged from a number of independent fields such as ethology, psychology, philosophy, and robotics (Shapiro, 2007). Nonetheless, there are family resemblances among embodiment theories and all, in one way or another, might be expected to emphasize the idea that our capacities for abstract mental representation are likely to build on the fact that we are biological beings who have concrete perceptions as well as bodies of a given type (Adams, 2010). The advantages of embodiment are several: Through the use of an embodied or grounded approach to representation, one can take advantage of the perceptual and motor achievements of the brain while avoiding the symbol grounding problem (Adams, 2010). That is, symbols or thoughts would likely lose their meaning if they had no links to more concrete experiences, such as those related to seeing, hearing, or touching (Lakoff & Johnson, 1999).

Experimental demonstrations of embodiment have abounded. Fischer et al. (2003) found that the presentation of small (large) numbers shifted attention to the left (right), consistent with the use of a spatial dimension to make sense of quantitative meaning. Pecher et al. (2003) found that participants were faster to verify that an object had certain properties (e.g., loudness, a certain taste) if the relevant sensory domain (e.g., hearing or tasting) had been repeated rather than switched across consecutive trials. Similarly, Hauk et al. (2004) found that hearing words pertaining to hand, leg, or facial actions activated the motor areas of the brain that would be involved in performing those actions. These and other findings have led to the suggestion that sensory simulations or embodied processes play important roles in human conceptual achievements (Glenberg, 2010).

In many cases, key theories of embodiment—such as those of Barsalou (1999) or Lakoff and Johnson (1999)—have been presented

in normative terms. That is, the field has mostly emphasized the manner in which all individuals should be similar in their use of perceptual simulations or in the use of grounding processes that can facilitate representational meaning (Glenberg, 2010). Yet, people have different bodies (Casasanto, 2011) and many of the processes that are implicated by such theories (such as simulation abilities or a preference for metaphorical thinking) almost certainly vary from person to person (Kosslyn et al., 2002). Accordingly, the consequences of embodiment are also likely to vary from person to person and the processes emphasized may be more prevalent among some individuals than others. Such individual differences can be important in theory evaluation (Kosslyn et al., 2002), but they can also be important in making the case for the long-term (or dispositional) consequences of the relevant processes or mechanisms (Fetterman et al., 2015a).

Pursuant of these ideas, the present chapter will examine correlational links between bodily factors and embodied cognition on the one hand and personality tendencies and psychopathology on the other. Part 1 of the chapter focuses on whether having certain types of bodies (e.g., tall ones or strong ones) predisposes individuals to having certain types of personality. Links of this type honor the idea that bodies matter for the sorts of cognitions and feelings that the individual should be prone to (Casasanto, 2011). Part 2 considers the question of whether embodiment-related ideas (such as those of Proffitt, 2006) can account for relationships between personality or psychopathology and perceptual processes. Part 3 will then consist of a systematic attempt to extend conceptual metaphor theory, which is a metaphorical theory of embodiment (Lakoff & Johnson, 1999), to the personality and individual difference domain. Part 4, finally, makes the case that embodiment itself may be a personality process. That is, certain individuals are more likely to rely on embodied signals than others and the relevant variations should matter for outcomes related to emotional experience and social cognition. In all areas of study, we will also touch on future directions that would benefit from additional research.

The Body as a Basis for Personality

A key premise of embodiment is that the bodies that we have are likely to play a key role in how we represent knowledge (Glenberg, 2010) and experience our lives (Lakoff & Johnson, 1999). If this is true, then people with different sorts of bodies should conceptualize the world in different ways (Casasanto, 2011), resulting in possible differences related to personality (Lahti et al., 2013). In many of these cases (e.g., birth weight or stroke paralysis), relevant links are likely to flow from physical to psychological, though some cases could also represent reversed directions of influence. Even so, bodily features, social perceptions, and personality tendencies are likely to reinforce each other, particularly over time, resulting in robust (though not necessarily strong) links between physical attributes and the diverse manners in which individuals think, feel, and act (Judge & Cable, 2004).

Relevant along these lines are data on birth weight and/or infant and childhood height and weight. Individuals with low weights and delayed growth patterns seem more vulnerable to both physical and psychological problems in later life, including in the domains of depression (Gale & Martyn, 2004), schizophrenia (Gunnell et al., 2005), and personality disorders (Lahti et al., 2011). Such influences have also been observed for all of the Big 5 personality traits aside from openness to experience (Lahti et al., 2013). For example, faster height and weight growth from birth to 6 months predispose the individual to higher levels of extraversion later in life (Lahti et al., 2013). The relevant mechanisms are thought to include reactions from parents and peers, which encourage exploration in the case of seemingly healthy physical development and discourage such exploration when the child appears small or feeble. Such processes can set the stage for lifetime trajectories of personality and social well-being (Lahti et al., 2013).

Height and size continue to matter through puberty and post puberty. In this connection, taller individuals are often viewed in ways that encourage interpersonal status (Hamstra, 2014). In fact, taller adults, and particularly males, are more likely to be chosen for leadership roles, achieving higher levels of salary as a result (Judge & Cable, 2004). Some of the relevant mechanisms are social cognitive in nature, in that taller heights seem to trigger perceptions of greater capacity, which has included attributions of charisma (Hamstra, 2014).

Through mechanisms of this type, taller individuals, like physically attractive individuals, seem to enjoy somewhat greater social status and success, including within the workplace (Hamstra, 2014; Judge & Cable, 2004).

In not unrelated terms, larger heights and weights have also been linked to antisocial personality tendencies, particularly among males. As an example, Farrington (1989) found that taller 8–10-year-olds were more prone to violent behavior at age 16–18. Similarly, Ishikawa et al. (2001) found that males diagnosed with antisocial personalities were larger and taller than men not receiving such diagnoses. An explanation for such links is that taller, larger men are more intimidating and they are also more likely to be successful when initiating physical violence (Ishikawa et al., 2001). Through social learning processes of this type, sizable men may learn that violence can produce desired results, leading to cognitive expectations that contribute to proactive aggression (Ishikawa et al., 2001).

In the animal kingdom, large, tall males tend to be more successful in procuring social resources and in defeating rival males within dominance hierarchies (Mazur, 2005). In addition to height and weight factors, postural cues are also relevant. Generally speaking, dominant individuals tend to adopt "larger" (e.g., standing upright) and more open (e.g., arms spread wide) body postures whereas submissive individuals tend to adopt "smaller" (e.g., crouching) and more restricted body postures (de Waal, 1998). Such links are evident among humans as well as apes and chimpanzees (de Waal, 1998) in that a meta-analysis has shown that human beings who possess more power or status are more likely to exhibit larger and more open body postures relative to those that are smaller and more restricted (Hall et al., 2005). Such postures are thought to trigger affective or motivational programs that encourage or discourage goal-pursuit (Price & Harmon-Jones, 2015) and they are also thought to affect the behaviors of others, shaping social interactions as a result (Toscano et al., 2018).

Relevant body posture studies were conducted by Fetterman et al. (2015b), who were intrigued by suggestions that arm-crossing may typically serve a defensive purpose (e.g., in protecting critical bodily organs such as the heart or stomach: Lewis, 2000). To examine processes of this type, Fetterman et al. (2015b) first asked participants

about their arm-crossing frequencies. As predicted, habitual arm-crossers were more submissive in their personality attributes as well as more cautious in their social decision-making. Subsequent studies then manipulated arm-crossing to establish the causality of the relevant processes. Consistent with the first study, participants induced to cross their arms (ostensibly as part of a social memory study) reported greater submissiveness and endorsed more defensive actions in response to hypothetical vignettes involving social threat. Hence, body postures can both follow from, and reinforce, personality tendencies related to the dominance-submission axis of interpersonal behavior.

Body comportment has also been implicated in depression in the form of at least two bodily signatures—a reduced walking speed and a slumped posture (Kraepelin, 1904). Consistent with clinical observations, manipulations of slumped body posture have resulted in greater behavioral helplessness (Riskind & Gotay, 1982) as well as in difficulties recovering from negative mood states (Veenstra et al., 2017). When depressed patients move, furthermore, they seem to do so more slowly, with additional reductions in arm swing and vertical head movements (Michalak et al., 2009). Such bodily signatures are consistent with a conservation of resources view (Proffitt, 2006) of depression and it is noteworthy that depressed symptomology can be caused by the relevant motoric patterns (Riskind & Gotay, 1982; Veenstra et al., 2017), suggesting bidirectional influences. With respect to the latter causal influences, some authors have suggested that postures alter self-perceptions of one's affective or motivational state (e.g., people infer that they are miserable when slumped: Riskind & Gotay, 1982) and others emphasize physiological processes such as postural influences on heart rate, respiration, or cortical or subcortical processing (Price & Harmon-Jones, 2015).

Another line of work has examined the personality-related consequences of reduced visual acuity and hearing. In an early publication, Thorington (1900) proposed that myopic individuals, with difficulty in seeing, tend toward later-life introversion. This seems to be true in that marked visual acuity deficits have been linked to lower extraversion scores, while marked hearing difficulties have been linked to higher levels of neuroticism (Coren & Harland, 1995). In both cases,

the deficits are thought to cause difficulties in social settings (e.g., with respect to detecting facial expressions or fully following conversations that occur), which eventually result in some degree of social withdrawal that alters personality functioning (Coren & Harland, 1995). Exactly why visual difficulties are linked to extraversion while hearing difficulties are linked to neuroticism is not entirely clear, but hearing difficulties could lead to concerns about missing auditory cues to danger, which could then give rise to a generalized state of fearfulness, as manifest in the trait of neuroticism (Coren & Harland, 1995).

With respect to the findings reviewed in this section, Casasanto (2011) has made the most explicit statements about embodiment. If the body matters for thought and feeling (Glenberg, 2010), then people with different types of bodies should think and feel differently, a premise termed the "body-specificity hypothesis" (Casasanto, 2009). The implications of this hypothesis have primarily been investigated with respect to handedness. When making lexical decisions about action verbs, right-handers displayed greater activation in the left premotor cortex, whereas left-handers displayed greater activation in the right premotor cortex (Willems et al., 2010). Moreover, approach motivation seems to be lateralized in a similar manner in that approach motivation covaries with left hemisphere involvement for right-handers, but right hemisphere involvement for left-handers (Casasanto, 2011). Thus, handedness can fundamentally alter the strategies that people use to deal with lateralized space.

Such processes are evident in implicit evaluations and decision-making. When two products or images are placed side-by-side, right-handers tend to prefer the right object to a greater extent, whereas left-handers are more likely to choose left-spaced objects, even when such choices are made verbally rather than manually (Casasanto, 2009). Gestures acquire a similar valence. Political candidates who are right-handed tend to use the right hand when emphasizing positive points and the left hand when emphasizing negative points. As predicted, though, such gesture-valence associations are reversed for left-handed candidates (Casasanto & Jasmin, 2010). These laterality effects seem to arise from fluency experiences. Right-handers, who are more fluent or capable with their right hands, subsequently come to view the right

side of visual space in more positive implicit terms. Such associations can be eliminated through strokes that affect the right side of the body or by asking participants to move objects with a right hand placed in a bulky ski glove. After practice of the latter type, right-handers subsequently prefer the left rather than right region of physical space (Casasanto, 2011). This line of research, then, highlights the key role that bodily experiences are likely to play in our conceptions of the environment.

The Brain as a Basis for Personality

The personalities that we have are almost certainly linked to the brains that we have, even structurally. General evidence for this point comes from studies linking larger brain volumes to higher intelligence levels (McDaniel, 2005) as well as studies showing that neurogenerative diseases result in personality changes (Pocnet et al., 2011). Additional recent studies have reported relationships between personality traits and the comparative volume of different brain structures. In this connection, DeYoung et al. (2010) were able to link four of the Big 5 personality traits to sensible brain volume patterns. As examples, the trait of extraversion correlated positively with the volume of the medial prefrontal cortex, which is involved in reward processing, and conscientiousness correlated positively with the volume of the lateral prefrontal cortex, which is involved in planning. The rationale for all such links is that larger brain structures of a given type (e.g., an emotional processing area) would facilitate one's capacities to handle the particular sources of information that the brain structure specializes in, shifting one's personality in a corresponding direction (DeYoung et al., 2010). Not all of these links have been replicated across studies, however (Kapogiannis et al., 2013).

More robust findings have been reported with respect to more circumscribed hypotheses. The cerebellum, which supports motor planning and motor behavior, may predispose individuals toward a more active, motoric approach to dealing with the environment. Consistent with this point, several studies (e.g., Petrosini et al., 2015) have shown that individuals with larger cerebellum volumes score higher in dimensions of temperament that favor action (e.g., novelty seeking) and score lower in dimensions of temperament that favor

action inhibition (e.g., harm avoidance). As noted by the relevant author teams, these results provide intriguing evidence in support of embodied perspectives on personality, inasmuch as the cerebellum is critically involved in voluntary body movements (Petrosini et al., 2015) and voluntary body movements are critical to a number of self-regulation processes that contribute to personality (Carver & Scheier, 1998).

Another productive line of inquiry has linked borderline personality disorder, which is marked by dysregulated emotional responding, to reduced volumes for two "limbic" brain structures—the hippocampus and the amygdala. Among borderline patients, the hippocampus is 14–23% smaller and the amygdala is 8–24% smaller, depending on the particular sample investigated (Nunes et al., 2009). Presumably, smaller volumes implicate reduced functionality and therefore greater susceptibility to at least one disorder that involves dysregulated emotional responding (Nunes et al., 2009). It is tempting to speculate that many more of these links between brain volume and personality will be discovered in the future, but success in this realm will probably require replication efforts and specific, theory-driven foci (Petrosini et al., 2015).

Summary

Table 21.1 summarizes some of the key evidence linking bodily (and brain) factors to personality traits and associated individual differences. It is clear that this is a productive line of inquiry, though it should also be apparent that these literatures tend to be somewhat isolated from each other rather than integrated. Elaborations of the body-specificity hypothesis (Casasanto, 2009) could be used to organize some of these literatures, though not all of them. Partially, this is due to the fact that different effects are probably due to different mechanisms, some of which involve concurrent relationships (e.g., the effect of slumped posture on depressed mood) and some of which involve longitudinal processes (e.g., the effect of body mass on the development of antisocial personality traits). Nonetheless, we have concentrated on relationships that are likely to involve causal relations from the body to one or more personality dimensions and future

research should increasingly attend to such causal directions as well as to questions about mechanism.

Table 21.1 The body as a basis for personality: representative findings

Body or brain factor	Key citation	Representative finding
Childhood height and weight	Lahti et al. (2011)	Faster growth from birth to 6 months is linked to later-life extraversion
Adult height (particularly among males)	Hamstra (2014)	Taller leaders are perceived to have more charisma
Body mass	Ishikawa et al. (2001)	Antisocial individuals have larger body mass
Open versus restricted body postures	Fetterman et al. (2015a, 2015b, 2015c)	Arm-crossing is associated with greater submissiveness and cautious decision-making
Depressed postures and movements	Michalak et al. (2009)	Depressed patients walk slowly, with less arm swing and vertical head movements
Visual acuity and hearing sensitivity	Coren and Harland (1995)	Poorer visual acuity is linked to introversion
Handedness	Casasanto (2009)	Left-handers prefer objects on the left and right-handers prefer objects on the right
Brain volume	McDaniel (2005)	Intelligent individuals have larger brains
Cerebellum volume	Petrosini et al. (2015)	Novelty seekers have larger cerebellum volumes
Volume of hippocampus and amygdala	Nunes et al. (2009)	Patients diagnosed with borderline personality disorder have smaller limbic brain structures

Embodiment in Personality and Perception

The idea that personality influences perception has a long history, though much of this research has been conducted from a Freudian perspective (Bruner, 1992). Independent of such influences, recent work has pointed to embodiment and metaphor as a basis for a number of personality/perception relationships. In one influential statement, Proffitt (2006) suggested that our perceptions scale to our capacities. Physically fit and energetic individuals should generally perceive movements through the environment to be easier because

they have the capacity to make those movements without signi cant costs. By contrast, less t and tired individuals should perceive distances to be longer and hills to be steeper, which would discourage them from problematic energy expenditures. Many studies have provided relevant support. As examples, Balcetis et al. (2015) showed that physically t individuals perceive distances to be shorter and Bhalla and Proftt (1999) showed that fatigued individuals judge hills to be steeper. Personality variables related to con dence and doubt (Carver & Scheier, 1998) might be expected to in uence energy-related perceptions as well, but relevant evidence along these lines is sparse.

The interface between personality and self-regulation has been broached in other ways, however. In a recent paper, Li and Cao (2019) asked Chinese participants whether past events were in front of them or behind them, using a cartoon character vignette. Conscientious individuals, who generally orient to the future and their future achievements (Zimbardo & Boyd, 1999), were more likely to place future events ahead of them rather than behind them, presumably because they intend to approach future events in an active self-regulatory sense. Participants with low conscientiousness levels, by contrast, placed the future behind them, possibly because they tend to orient to the past rather than the future. Along somewhat similar lines, Fetterman et al. (2015c) found that participants differed in which types of stimuli they sought to approach and that these approach-worthy stimuli acquired properties that would facilitate goal attainment (e.g., faster recognition and larger perceptual size). Even so, more work on the interface between personality and self-regulatory perceptions would be useful.

Some of the most compelling work on the personality-perception relationship has concerned individual differences in depression and anxiety. In a content analysis of a memoir written by a depressed writer (which was, in fact, titled ***Darkness Visible***), Schoeneman and colleagues (Schoeneman et al., 2004) found that the author used some 1383 metaphors to describe his struggles with depression and its in uences. These metaphors were rich and vivid as well as personal, but they were also somewhat conventional (Gibbs, 1994). Depression was described as a vicious foe that one must struggle with who trades in death, darkness, and that which is down (e.g., holes in the ground

that would trap one). Recovery, by contrast, seems heavenly in that it is up and light, while bringing peace and safety. Interviews with depressed patients have produced somewhat equally compelling—and strikingly similar—portrayals. According to patients, depression is descent rather than ascent, darkness rather than light, and weight or force that is trying to press one down (Charteris-Black, 2012).

These (Charteris-Black, 2012; Schoeneman et al., 2004) portrayals are worthy of study because they make a strong case for a perceptual basis to the depressive experience while also highlighting relevant hypotheses. In one pertinent study, Barrick et al. (2002) found that depressive individuals were much more likely than non-depressive ones to agree with the statement that the world seemed gray or drab or lacking in color. Barrick et al. (2002) speculate that retinal factors may be responsible for this relationship, but top-down influences on perception (Stefanucci et al., 2011) seem more likely. In either case, further perceptual work seems indicated. With respect to relationships between the depressive experience and verticality, Meier and Robinson (2006) showed that more depressed individuals tended to deploy selective attention in a downward- (rather than upward-) favoring direction. To our knowledge, other apparent components of the depression experience (such as the perception of containment or struggle or being burdened with heavy weight) have not been investigated.

There is a larger body of work on anxiety and perception, however. Participants who have a fear of heights, as well as emotionally aroused individuals, tend to perceive that distances to the ground are longer when viewing them from above (e.g., Teachman et al., 2008). Similarly, being placed on a skateboard, which is much less stable than walking, renders downward slants seemingly steeper (Stefanucci et al., 2008). Such biases are likely to serve a self-regulatory function in that concerns about gravity or height could dissuade one from taking unnecessary risks (Proffitt, 2006; Stefanucci et al., 2011). At the same time, though, a negatively biased perceptual system could render one more vulnerable to anxiety and fear, which are aversive emotional states (Watson & Clark, 1984).

Another perceptual model of fear was proposed by Riskind and colleagues, beginning in the 1990s (Riskind et al., 1992). According to

this “loomingness” model, fearful individuals tend to be biased to perceive threatening objects to be larger, more imminent, and more quickly moving toward the self than they actually are. Biases of this type are perhaps most intuitive in the case of animal phobias as data have shown that phobic individuals, relative to non-phobic individuals, perceive snakes and spiders to be moving toward the self at a faster rate (e.g., Basanovic et al., 2019). They also perceive such stimuli to be larger (e.g., Leibovich et al., 2016). Beyond such phobic processes, Riskind and colleagues have argued that some version of loomingness could underlie many forms of fear and anxiety, which would add a perceptual component to the genesis of such states and tendencies (Williams et al., 2005).

Some of these distance-related dynamics could operate in a different way, though. People who are anxious are generally concerned about possible threats to the self and they should generally adopt distance-enhancing strategies to avert them (Carver et al., 2000). As a result of this avoidant style of self-regulation, practiced individuals may eventually perceive events or stimuli to be further away from them, relative to individuals adopting more approach-oriented forms of self-regulation (Carver & Scheier, 1998). Liu et al. (2013) provided support for these ideas in a number of studies that asked individuals to estimate temporal distances, stimulus sizes, and the relative speeds of growing and shrinking stimuli. Neurotic individuals, who are more prone to states of fear and anxiety (Watson & Clark, 1984), perceived future events to be further away from them, objects to be smaller, and stimuli to be shrinking faster than they were growing. Hence, the perceptual signature of neuroticism could be one that favors avoidance rather than approach (Liu et al., 2013).

In reconciling the Liu et al. (2013) data with the Riskind model, it seems possible that object-evoked fears are relevant. In relatively mundane cognitive tasks (Liu et al., 2013), objects will not evoke fear. Such circumstances should engender perceptions that the avoidance system is “working”, resulting in perceptions of greater distance (Carver et al., 2000). When a stimulus evokes fear, however, avoidant individuals are likely to gain the sense that the avoidance motivation system is not working, resulting in perceptions that threats are imminent (Basanovic et al., 2019). Similar dynamics have been shown

in the attentional bias literature (MacLeod, 1999), which should encourage further work on this anxiety-perception interface.

Summary

Although work on the resource-based model of perception (Proffitt, 2006) has generally focused on temporary manipulations such as wearing a heavy backpack, there are increased suggestions that individual differences matter as well (e.g., Balcetis et al., 2015). Because personality psychology is the field of psychology centrally concerned with individual differences, there should be more integration of the personality and perception literatures (Fetterman et al., 2015a). For example, it stands to reason that personality dimensions such as self-esteem could be integrated into a resource-based framework, given that self-esteem captures differences related to self-beliefs of capability (Carver & Scheier, 1998). Another point worth making is that this area of investigation has produced discrepant findings—such as concerning whether threatening objects tend to appear closer to or further away from the self than non-threatening objects (Balcetis, 2016). Taking personality factors into account may resolve such discrepancies because individuals vary quite a bit in the motivations thought to underlie the perceptual phenomena that have been investigated (e.g., Li & Cao, 2019).

Explorations of Conceptual Metaphor and Personality

Metaphors for the head and the heart abound. The head trades in rational thinking, skepticism, and logic, whereas the heart operates by experiences, feelings, and compassion. The heart seeks to connect and the head seeks independence, much as masculinity does (Bakan, 1966). Ascribing such qualities to the head and the heart are not recent. Plato (trans. 1987) viewed the heart in terms of passion and the head in terms of rationality many centuries ago and versions of these ideas can be found throughout history, both in the English (Swan, 2009) and Chinese (Yu, 2003) narrative traditions. Metaphors for the head and the heart speak to a duality in our existence (Epstein, 2003), but they

also serve a critical embodiment function: The self must exist somewhere within its body and the head and the heart are the most plausible loci. In support of this point, Limanowski and Hecht (2011) asked participants to locate the self in a human silhouette and the head area and the heart area were the dominantly chosen regions.

However, Limanowski and Hecht (2011) also found that individuals differed in their choices, with some choosing the head region and some choosing the heart region. Such choices are likely to be consequential. To envision the self in the head should lead one to view the self as a rational and somewhat cold entity; by contrast, to envision the self in the heart should lead one to view the self in emotional or feeling-based terms. Intrigued by ideas of this type (Lakoff & Johnson, 1999), Fetterman and Robinson (2013) asked many samples of participants whether they more closely associate the self with the brain (head) or with the heart. Attesting to the individual difference value of the measure, an approximately equal percentage of participants chose each bodily organ. Furthermore, and consistent with data indicating that women value intuition and feeling to a greater extent (Epstein, 2003), most studies have found sex differences, such that about 60% of women are heart-locators and about 60% of men are head-locators (Fetterman et al., in press; Fetterman & Robinson, 2013).

Self-locations can also serve as an implicit measure of personality in that one's self-location, whether embodied or metaphorical, is likely to matter for the sort of personality that one has. To examine this possibility, participants have been asked to report on a number of personality qualities in a number of studies (several of which are presented in Fetterman & Robinson, 2013) and we emphasize two key distinctions here. Participants have been asked to indicate their degree of emotionality (e.g., "I am an emotional person") as well as logic (e.g., "I am a logical person"). Participants have also been asked to rate the extent to which they are warm (e.g., "I am a warm person") and cold (e.g., "I am a cold person") in their interpersonal relationships. As shown in Fig. 21.1, both emotionality and warmth tend to be higher among heart-locators, whereas both logical thinking and coldness tend to be higher among head-locators. These results are consistent with metaphors for the heart and the head, which emphasize these exact sorts of qualities (Lakoff & Johnson, 1999; Yu, 2003).

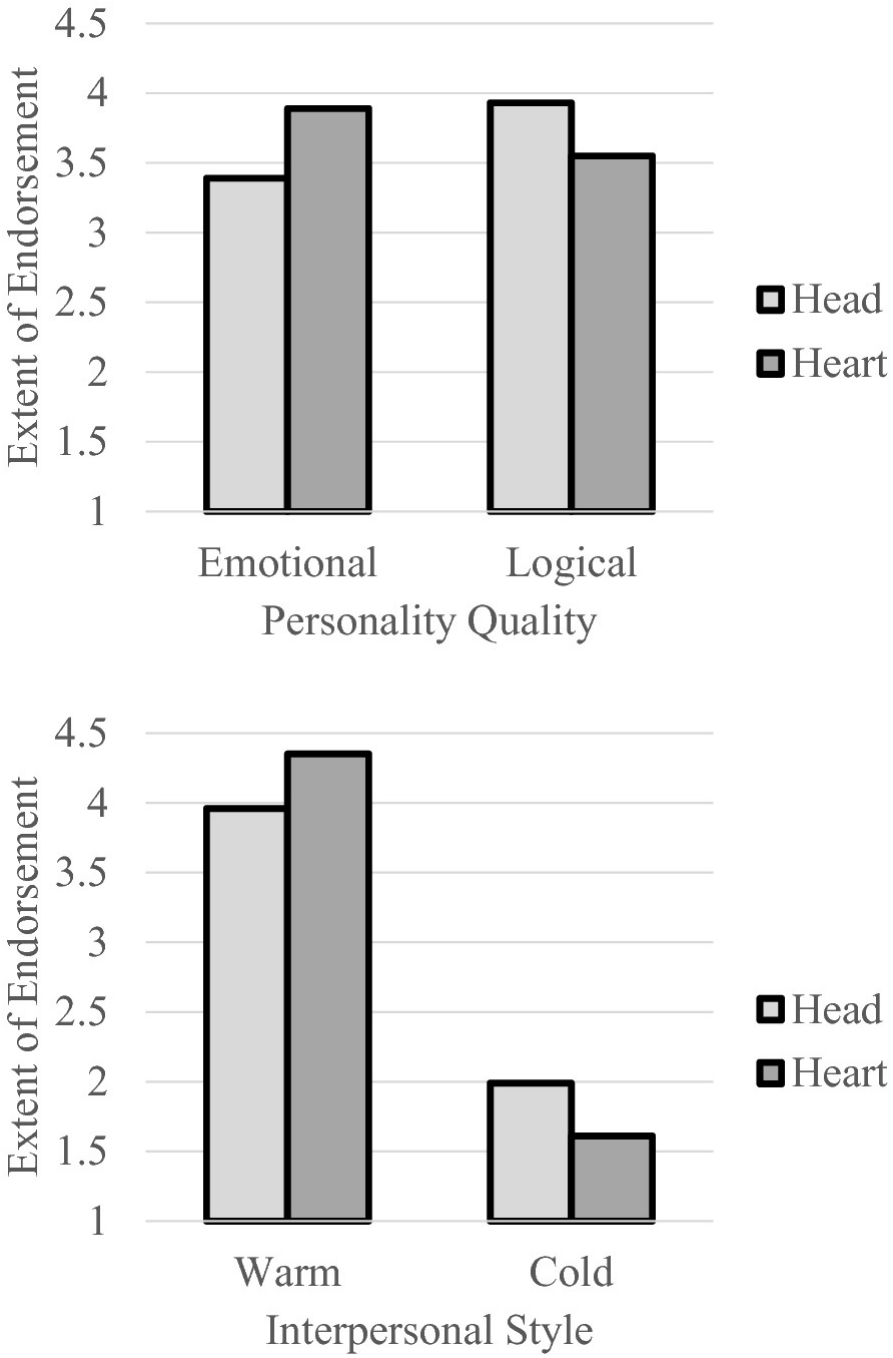


Fig. 21.1 Tucson self-location as a predictor of personality qualities and interpersonal style (re-graphed data from Fetterman & Robinson, 2013)

Nonetheless, metaphors for the head and the heart tend to reference thinking styles to a greater extent than personality qualities. A person who "thinks with her head" is a person who is rational if not skeptical and a person who "follows her heart" is a person who fully commits to her passions (Lakoff & Johnson, 1999; Swan, 2009). Such

thinking styles should matter for realms in which logic alone cannot justify a particular belief system or course of action. For example, heart-locators may experience stronger passions and more certainty in the context of their budding romantic relationships (that may or may not work out).

Rather than focusing on the relationship realm, Fetterman et al. (in press) focused on religious beliefs. To believe in God is to believe in something that cannot be logically proven, yet may be of great comfort in alleviating existential fears (Atran & Norenzayan, 2004). Fetterman et al. (in press) proposed that heart-locators should be much more willing to make the "leap of faith" that religious beliefs require, whereas head-locators would be more skeptical or agnostic. Five studies supported these hypotheses and two of them showed that relationships of this type were mediated by intuitive thinking styles. That is, heart-locators are more prone to intuitive thinking, including in moral domains (Fetterman & Robinson, 2013), and intuitive thinking favors religious belief (Baumard & Boyer, 2013). Through processes of this type, self-location should also matter for other outcome domains in which feelings and desires can conflict with a more rational (or interpersonally colder) analysis of the situation.

Extending Conceptual Metaphor Theory Through the Use of Balance Principles

The self plays a powerful role in anchoring preferences and attitudes, though we are often unaware of the extent to which this is true (Greenwald & Banaji, 1995). For example, the mere ownership of an item renders us more favorable to it, even when its attributes are substandard (Greenwald & Banaji, 1995). Similarly, enrollment in a particular school leads us to shift our general color preferences in ways that favor one's school colors over those of the rival school (Schloss et al., 2011). More perniciously, perhaps, identifying as a woman leads women to distance themselves from career opportunities that involve stereotypically male subjects, such as math or science (Nosek et al., 2002).

In recent work, we have been able to use such balance-related (Cvencek et al., 2012) ideas to extend conceptual metaphor theory (CMT), which tends to emphasize normative associations (Lakoff &

Johnson, 1999), to a consideration of personality processes. Briefly, this "balanced" version of CMT (Fetterman et al., 2017) proposes that preferences for a metaphor-rich object or perception (e.g., dark colors, sweet tastes) should predispose individuals toward experiences and behaviors that are metaphorically consistent with that object or perception. For example, individuals who identify with "dark" colors and cultures (e.g., the Goth culture) should become increasingly prone to states or traits, such as depression and pessimism, that are metaphorically linked to darkness (Persich et al., 2019).

A more formal presentation of this theory is depicted in Fig. 21.2. As shown there, we begin with the metaphorically strong relationship between sweetness and prosociality (bottom line of each triad), as manifest in phrases like a "sweet person" or a "sweet gesture" (Meier et al., 2012). To the extent that a person likes sweet foods quite a bit, balance dynamics should favor greater prosociality (top panel). Individuals who do not like sweet foods, however, should not be prone to experiences and behaviors that are metaphorically linked to sweetness, such as prosociality (bottom panel). We should emphasize that the relevant dynamics can be subtle (Greenwald & Banaji, 1995). Nonetheless, the mind should seek balance between its self-concept, which is linked to personality (Robinson & Sedikides, in press), and its attitudes concerning objects or perceptions that have a metaphorical basis to them.

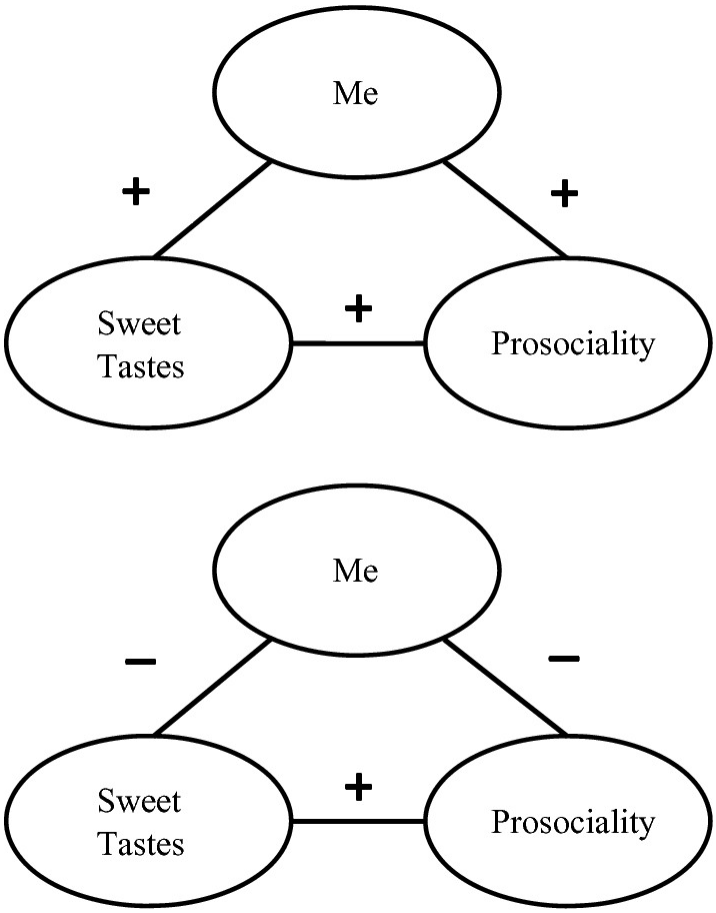


Fig. 21.2 Sweet foods and the self: balance dynamics favoring greater (top panel) and lesser (bottom panel) prosociality (based on the conceptual analysis of Fetterman et al., 2017)

Consistent with such theorizing, Meier et al. (2012) found a positive relationship between the personality trait of agreeableness, which is strongly linked to prosociality (Jensen-Campbell et al., 2010), and preferences for sweet food. That is, agreeable people liked sweet foods to a greater extent than disagreeable people did. Moreover, sweet food preferences predict prosocial behaviors, both correlationally and experimentally (Meier et al., 2012). Relatedly, Fetterman et al. (2017) found that people were nicer to others on days that they consumed sweet foods, and the resulting links could not be explained in terms of mood states or self-control processes. Thus, metaphoric associations can become personality processes, precisely because they affect how the self thinks about itself (Robinson & Fetterman, 2014).

A related series of studies have shown that similar predictions can be made concerning preferences for light or dark (which seem to

convey “goodness” and “badness” in a universal way: Adams & Osgood, 1973). Participants who prefer the perceptual concept of darkness over the perceptual concept of light are systematically more pessimistic, depressed, and anxious (Persich et al., 2019). These findings are consistent with metaphors for darkness, which link darkness to pessimism and negativity (Forceville & Renckens, 2013). By contrast, individuals who prefer light to darkness tend to believe in God to a greater extent (Persich et al., in press), which is consistent with universal religious symbolism linking divinity to lighter rather than darker colors and perceptions (Eliade, 1996). Hence, metaphor-linked preferences appear to predispose people to metaphor-linked personalities and experiences.

Summary

That individuals differ in their perceived self-locations is a fascinating discovery, but much work remains. Fetterman and Robinson (2013) examined the test-retest stability of self-locations across time and found that some individuals had switched self-locations during the relevant time period. It would be useful to know what triggers such shifts and whether the self might exhibit even more malleable self-locations as a function of daily activities (e.g., talking to a loved one versus studying for class). Fetterman et al. (in press) studied the decision-making correlates of self-location, but only in a single domain. We therefore need more research of this type, particularly in the relationship domain. The second line of research used balance principles (Cvenzek et al., 2012) to expand conceptual metaphor theory, but certain critical components of “balanced CMT” (Fetterman et al., 2017) would benefit from additional research. A long-standing question in balance theory is what would happen if a person did not particularly like him/herself. Under such circumstances, the self’s preferences would not necessarily constrain third variables in the manner that we have described (Heider, 1958). More could be done, then, to incorporate features of the self-concept (such as self-esteem) into this research.

Individual Differences in Embodiment

An assumption in embodiment research is that everyone thinks or feels in embodied terms (e.g., Lakoff & Johnson, 1999). However, this assumption could be somewhat faulty and embodiment itself could be an individual difference. That is, some individuals, more than others, could be attuned to signals from the body and to the perceptual-conceptual interface. A relevant framework is the "somatic marker hypothesis", which posits that individuals use signals from the emotional processing regions of the brain to make decisions (Damasio et al., 1996). In a well-known set of studies, Damasio et al. (1996) discovered breakdowns in this process among patients with ventromedial prefrontal brain damage. Even in the absence of such damage, though, individuals should differ in the functionality of the relevant circuits, as has been hypothesized for disorders such as psychopathy (Blair, 2010).

On the more functional side, too, theory and research has converged on certain personality traits that should play a role in embodied processing and its relevant achievements. Along these lines, Epstein (2003) proposed individual differences in experiential processing, defined in terms of processing that favors intuitive inputs from the body and mind. Individuals who endorse experiential thinking styles might be expected to display greater embodiment (Epstein, 2003). So might mindful participants, who should be more attuned to low-level affective signals arising from brain regions such as the anterior cingulate (Teper et al., 2013). Relatedly, Mayer and colleagues have proposed a number of "hot intelligences"—such as emotional intelligence—that are thought to involve sensitivity to bodily signals (Mayer et al., 2016).

A relevant model is interoceptive awareness, defined in terms of awareness of afferent input from the body (Cameron, 2001). Interoceptive awareness is reliant on brain structures such as the insula, which process bodily and sensory signals in a manner that can support representation and decision-making (Critchley et al., 2004). Interoceptive awareness is typically assessed by some version of the heartbeat detection task, which seeks to determine whether individuals can effectively monitor their heartbeats, especially at rest (Critchley & Garfinkel, 2017). There are pronounced individual differences in such abilities, so much so that it appears that only some

individuals could be said to be interoceptively aware according to these tests (Herbert & Pollatos, 2012). And, such abilities matter.

Generally speaking, it appears that interoceptively aware individuals have more intense emotional reactions, especially in response to stimuli that are known to be emotionally arousing (Dunn et al., 2010). They also display a greater covariation between heart rate and emotional arousal (Pollatos & Schandry, 2008) and exhibit larger P300 responses to both pleasant and unpleasant pictures (Herbert & Pollatos, 2012). By contrast, individuals lacking interoceptive awareness display lesser sensitivity to the arousal dimension of emotional experience (Barrett et al., 2004) and it is likely that they process emotional stimuli in a more semantic, less embodied, manner (Herbert & Pollatos, 2012).

Although intense emotional experiences may not always be desirable, interoceptive awareness appears to support some functional achievements. Participants who are interoceptively aware (as assessed through heartbeat detection performance) are better at recognizing the emotions of others (Terasawa et al., 2014), which is a skill linked to emotional intelligence (Mayer et al., 2016). Related results have shown that interoceptively aware participants are more sensitive to the pain of others, which leads them to experience greater empathy and compassion (Grynberg & Pollatos, 2015). Finally, some experimental work has shown that interoceptively aware participants are less vulnerable to bodily illusions such as the rubber hand illusion (Herbert & Pollatos, 2012).

Further pursuing this functional theme, deficits in interoceptive awareness have been posited for a number of clinical conditions. Anorexic patients, it has been theorized, may have deficits processing hunger signals, which could contribute to their disorder (Herbert & Pollatos, 2012). Individuals prone to schizophrenia are also thought to have impoverished representations of the bodily self, which could contribute to the sense that one is a machine rather than an organic entity (Stanghellini, 2009). Alexithymic individuals exhibit poorer performance in interoceptive awareness tasks (Herbert et al., 2011) and embodiment deficits have also been highlighted in autistic spectrum disorder (Critchley & Garfinkel, 2017). Among the latter deficits seem to be deficits in facial feedback processes (Stel et al.,

2008). In sum, individual differences in interoceptive awareness, which is an important component of embodiment, may be substantial as well as consequential.

Summary

There may be important ways in which embodiment-related processes differ across individuals, as has been suggested with the "somatic marker" hypothesis (Damasio et al., 1996). However, there does not seem to be enough research of this type, particularly given its importance with respect to long-standing questions about the mind-body interface. It is fortunate that there is a test—the heartbeat detection test—that can be used to assess individual differences in interoceptive awareness. But, this test is somewhat limited in scope and there are questions about how the relevant abilities relate to other forms of interceptive processing (Herbert & Pollatos, 2012). In this connection, we would recommend additional research using other probes of sensory sensitivity (e.g., taste sensitivity) or imagery ability. The latter individual differences, in particular, might be expected to moderate phenomena that have been ascribed to perceptual simulation processes (Barsalou, 1999).

Conclusions

As a way of summarizing some of the themes of this chapter, we note that conceptual metaphor theory has proposed that all individuals think metaphorically (Lakoff & Johnson, 1999), which involves drawing from embodied experiences to scaffold more abstract forms of thinking (Robinson & Fetterman, 2014). Lexical analyses, however, do not support the universality of metaphor in that many sentences do not involve metaphors, even when liberal criteria are used to classify metaphoric constructions (Graesser et al., 1989). Furthermore, multiple theorists have suggested that metaphors can be problematic (e.g., Rorty, 1989) and that there are probably pronounced individual differences in both the use and appreciation of metaphoric forms of thinking and speaking (Bucci, 1984; Epstein, 2003).

Such precedents led to the development of a Metaphor Usage Measure (MUM), which pairs literal and metaphoric phrases (e.g., "I am

impatient" versus "I am fed up") and asks individuals which statement they would be more likely to say, think, or write in everyday life (Fetterman et al., 2016). The mean of the scale typically straddles the midpoint, suggesting that some individuals favor literal thinking and others like to think metaphorically. Furthermore, individual differences in the relevant processes are consequential: Although metaphor users are more prone to erroneous metaphoric inputs (e.g., whether they did or did not eat sweet foods on a given day), they also exhibit a greater degree of emotional understanding (Fetterman et al., 2016). In other words, there appear to be both benefits and costs to metaphoric thinking, as may be true of embodiment processes more generally.

What have been conceptualized as universal embodiment effects, then, could well turn out to mask substantial individual difference heterogeneity (Kosslyn et al., 2002). Not everyone possesses even adequate levels of interoceptive awareness, for example, and the relevant differences seem pertinent to the emotional intelligence construct (Grynberg & Pollatos, 2015), which itself involves individual differences (Mayer et al., 2016). In the present chapter, we have developed some of these themes while also documenting ways in which our bodies, which are different from each other (Casasanto, 2011), may predispose us to different sorts of personalities. Effect sizes are not always large and the relevant data cannot be summarized with any one theoretical perspective (Shapiro, 2007). Nonetheless, individual differences seem important to consider in any complete account of embodied influences on thinking, feeling, or behaving.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_22

22. Embodiment in Clinical Disorders and Treatment

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Abstract
Traditional social cognitive and cognitive-clinical perspectives have assumed that thinking (or cognition) and information processing play key causal roles in emotional and clinical disorders. Misappraisals and faulty attributions, assumptions, and beliefs, and cognitive activity such as rumination and worry, are the focus of clinical interventions. However, in recent decades, it has become increasingly recognized that the links between cognition and bodily states are mutual and reciprocal. That is, it is not just that an individual's cognition influences body states and emotion, but the individual's body states and emotions can also influence their cognitive processes in return. The links between cognition, emotion, and bodily states are fundamentally bidirectional and complex and it may be important to consider the impact of emotion and bodily states in cognitive changes. Thus, strategies from embodied or body-oriented approaches may help to

augment CBT strategies to produce better treatment outcomes. The rapidly growing literature on embodiment science has the intriguing potential to afford new insights for understanding and treating clinical disorders.

Keywords Embodiment – Clinical disorders – Treatment – Embodied CBT

Chapter in M. D. Robinson and L. E Thomas (Eds.), ***Embodied Psychology: Thinking, Feeling, and Acting***. Springer Nature.

Embodiment in Clinical Disorders and Treatment

According to cognitive-behavioral models of clinical disorders and treatment, clinical disturbances such as depression, anxiety, insomnia, or even schizophrenia are created and maintained, at least in large part, by distorted cognitive processes and cognitions. Cognitive-Behavioral Therapy (CBT) has been very successful and is considered a preferred "Gold Standard" treatment for many disorders (Butler et al., 2006). However, a sizeable percentage of patients do not respond to treatment or later relapse (Cuijpers et al., 2014; Hofmann & Smits, 2008). Among the many factors that may help to explain this, the limitations that have emerged may at least partially reflect inadequate attention to the embodiment of mental states and the complexity of links between human thought and the body.

The embodiment literature may provide an important avenue for the possible improvement of CBT because it suggests that body movements, postures, facial expressions, and other bodily states do not just represent internal mental states and cognitions, but have a reciprocal impact on these. Support for the embodiment of mental processes has amassed from diverse perspectives in the cognitive sciences, cognitive neurosciences (Damasio, 1999; Tagini & Raffone, 2010), psychology (Anderson, 2003; Barsalou, 2008; Niedenthal et al., 2005), as well as linguistics (Lakoff & Johnson, 1999), and philosophy (Varela et al., 1991). The common thread that runs through these various approaches is that bodily states may not just reflect how

people feel, but additionally play a major role in influencing how they feel and how they go about making sense of themselves and the world. Reviewing this literature, the present chapter suggests that merging embodiment approaches with CBT may have promise in potentially helping to advance its future development and augmenting the efficacy of its treatment outcomes. The present chapter begins with a brief review of the theoretical foundations of CBT before turning to theories and research on embodiment. Subsequently, it considers the contribution that embodiment may make to the conceptualization of CBT and the treatment of clinical disorders.

Theoretical Foundations of CBT

Early CBT approaches (as opposed to strictly behavioral ones) were initially shaped by the dominant computer metaphor that shaped understanding of the nature of cognition at the time. Cognition, much as with the computational activity of a computer, was understood as involving the processing of symbols and stored information that was essentially devoid of the nitty–gritty of lived sensory experiences (e.g., the person's visual, auditory, olfactory, kinesthetic senses). Concepts and mental representations used in human thought were considered to be independent of the sensory-perceptual and motor systems from which they were originally derived. The majority of social-cognitive models that emerged in this era, such as cognitive appraisal models and attributional models (e.g., Kelley, 1973; Lazarus, 1991; Schachter & Singer, 1962; Weiner, 1985), had roots in the computer metaphor and prioritized the causal roles of human thought and cognitive processes (e.g., cognitive appraisals, attributions, attention, and memory). Under such models, events or stimuli were the input and emotional reactions and bodily responses to events were the products or outputs of cognitive processes, and the body was not a determining shaper of cognition.

Cognition in Clinical Disorders

In the case of clinical disorders, the attributional model of learned helplessness and depression which was advanced by Abramson et al. (1978) was based on social cognitive models of the causal attribution

process (e.g., Kelley, 1973; Weiner, 1985). This initial social cognitive model, in turn, was subsequently elaborated by Abramson et al. (1989) into the contemporary hopelessness theory which has garnered considerable support as a model of depression.

Beck and his colleagues have advanced the dominant cognitive clinical formulation of psychopathology and clinical treatment that prevails today (e.g., Beck, 1976; Clark & Beck, 1999). The key feature of this formulation is that it underscores the etiological roles of maladaptive cognitive processes in emotion and behavior. Beck's model assumes that a person's dysfunctional beliefs about the self, others, the world, and the future (cognitive schemas) mold the person's subjective construals and interpretations of events (even those that are relatively neutral) and distort their meanings, ultimately serving to produce and maintain clinical disorders.

Under such views, cognitively oriented clinicians maintained that behavior therapy interventions such as exposure worked largely because behavioral changes are vehicles for producing cognitive changes. They produce changes in expectations and beliefs (Salkovskis, 1991; Wells et al., 1995).

Embodiment in CBT Approaches

CBT approaches have focused largely on modification (or restructuring) of expectations and beliefs that are or can be expressed in verbal-conceptual terms. While these approaches have given some attention to the role of mental imagery, they have paid nominal attention to the possibility that thought processes can be affected by expressive behaviors, postures, gestures, gait patterns, or other bodily responses. In so doing, moreover, they have not considered the possibility that human thought processes may not solely involve operations that occur/or are contained within the skull.

Theories of the Embodied Mind

James (1922) offered one of the earliest modern perspectives to contend that feedback from bodily responses was integral to the experience of the human mind. James (see also Neo-Jamesians such as Izard, 1972; Tomkins, 1962) proposed the then more controversial idea

that feedback from bodily changes in the face, skeletal muscles, or viscera were integral to emotion (e.g., we are happy because we smile, and the smiling is the feeling of emotion).

Subsequently an increasing number of cognitive scientists (Anderson, 2003; Barsalou, 2008; Glenberg et al., 2013) and cognitive neuroscientists (Damasio, 1999; Tagini & Raffone, 2010) have proposed that body states are integral to cognition. As Glenberg and colleagues (2013, p. 573) stated, cognition is "not something that is divorced from the body, but rather, thinking is an activity strongly influenced by the body and the brain interacting with the environment." For example, a person's mental representations of a teacup incorporate sensorimotor information and "action-based" meaning (e.g., "muscle memory") of the movements involved in the teacup's use.

According to Barsalou's (2008) influential perceptual symbol system model (PSSM), cognition is integrally linked to the perceptual and sensorimotor simulations or "re-enactments" of actions and interactions that individuals have with their environments. When one's stored knowledge is used during the course of thinking (e.g., remembering the meaning of the concepts of "tall" or "short"), this activates one's patterns of neural activation involved in the sensorimotor experiences associated with the memory. Consider, for example, the case when one is thinking about someone who is tall: one lifts one's head as if looking up to see them; while when one is thinking about a person who is short, one lowers one's head as if looking down to see them. Furthermore, the influence is mutual and reciprocal. Body states and movements can activate corresponding thoughts or concepts. For example, when one is smiling, this can activate positive thoughts and concepts linked to smiling.

Multiple mechanisms exist by which body responses may influence human thought processes. As suggested by Briñol and Petty (2008), body responses may provide simple self-perception cues for interpreting events; for example, if one smiles, one gets feedback that stimuli that one is responding to are positive (Laird, 1974); in addition to this, they may also provide information that self-validates or invalidates one's beliefs and attitudes (e.g., nodding one's head conveys to oneself that one is in agreement with what is said or what

one is thinking). Bodily responses can also activate mental states through their links in associative networks. For example, if one happens to smile or frown, this may activate information that is a facet of one's associative networks through spreading activation.

A further major mechanism is that sensorimotor states and prior sensorimotor experiences with the world (e.g., of warmth of heaviness) may serve by providing our minds with a scaffolding of simpler concrete analogies or metaphors used as building blocks for developing increasingly more complex concepts for thinking and understanding (Lakoff & Johnson, 1982; Landau et al., 2010; Williams et al., 2009). As Lakoff (2015) recently stated, "Everyone living on earth has experienced the world, we have all experienced gravitation. Further, these primal physical experiences with the world provide the superstructure for all the conceptual systems that people develop thereafter."

Empirical Studies of Embodiment Feedback

Empirical support for embodiment perspectives has come from studies on the feedback effects of experimental manipulations of facial expressions, postures, gestures, and other movements and sensory experience (see other chapters in this volume for more comprehensive reviews).

Facial Feedback

Building on the precedent of earlier studies by Laird (1974) and others, Strack et al. (1988) reported an influential study showing that participants rated cartoons as more humorous when they were instructed to hold a pen between their teeth, to indirectly induce them to smile, than when they were instructed to hold a pen between their lips, to induce them to frown. Despite studies that have sharply challenged these findings (e.g., a meta-analysis by Wagenmakers et al., 2016), substantial evidence that supports facial feedback effects has been gathered. A meta-analysis by Coles et al. (2019) on a much larger number of studies than assessed by Wagenmakers et al. provided evidence that supports the validity of facial feedback, although the observed effect sizes were heterogeneous and sometimes small.

Postural Manipulation

Since postural feedback effects were initially reported in the 1980s and 1990s (Riskind, 1984; Riskind & Gotay, 1982; Stepper & Strack, 1993), scores of studies have examined the impact of postural manipulation. These have included an influential study by Carney et al. (2010) about ten years ago that provoked a surge of interest and controversy in the feedback effects of "power posing." Their study reported that when participants were led to adopt an open expansive posture (a "power pose"), this had a significant impact in increasing their subjective states and behavior (e.g., risk tolerance) related to feelings of power as well as on neuroendocrine changes. However, their findings were followed by reports of failures to replicate by Ranehill and colleagues (2015) and others, and serious questions emerged about whether Carney et al. (2010)'s findings were flawed by selective reporting or p-hacking (Simmons & Simonsohn, 2017).

Whatever the limitations of specific studies, research since then has provided considerable evidence that supports physical posture feedback effects (e.g., Cuddy et al., 2018; see Elkjaer et al., 2020 for a meta-analysis). However, it is true that postural manipulations may have only small to moderate impact on mental states and primarily on self-report measures of subjective feelings of power. It should also be noted that Elkjaer and colleagues' recent meta-analysis indicates that the "power posing" effects on affective and behavioral responding may be due to the absence of contractive postures rather than the presence of expansive power displays.

In addition to the above studies, a few studies have shown that a forward versus backward body lean has feedback effects on the extent to which individuals are open and willing to consider new information in decision making and attitudes. In particular, Shirasuna et al. (2019) documented that participants who were in a forward-leaning posture were more willing to choose to donate organs post-mortem and more willing to accept new ideas and advice from others.

Feedback from Tensing or Relaxing Fists and Other Skeletal Muscles

Schubert's (2004) studies have indicated that feedback effects from fist clenching have an impact on feelings of power. Coupled with Schubert's

studies, an earlier study reported by Jo and Berkowitz (described in Berkowitz, 2000) also indicated effects of fist clenching (versus relaxed hands) on mood following a mood induction of angry versus sad affect.

Feedback from instructions to participants to tense muscles may also have influence on their subjective feelings of self-control. Hung and Labroo (2010) documented that instructing participants to firm their muscles during tasks (such as when choosing between healthy food and tempting but unhealthy food) led them to exhibit more self-control than those who did not firm their muscles.

Motoric Movement

In tandem with studies of feedback from fist clenching and facial and postural manipulation, several studies have shown that feedback from aspects of motoric/bodily movement such as gait have an impact on mental states (see meta-analysis by Elkjaer et al., 2020). For example, Michalak and colleagues (2015) reported finding that participants who were without depression and who were instructed to walk in a happy manner displayed a memory bias for positive information over negative information, whereas those instructed to walk in a depressed manner showed a muted memory bias in this direction. It has also been reported that approach/avoidance body movements (e.g., swiping one's arms toward or away from the body) have an influence on evaluations and judgments. Specifically, swiping or bringing positive images toward one's body increased positive evaluations and judgments. More positive evaluations and judgments were not observed when participants were instructed to swipe or push positive pictures away from one's body, or when swiping or bringing negative pictures closer toward one's body (Cervera-Torres et al., 2019).

Feedback effects of experimentally instructed head nodding have also been shown to increase participants' confidence in the contents of their thoughts, whereas instructed head shaking reduced such confidence in their thoughts (Briñol & Petty, 2003). Feedback from head nodding has also been found to increase preferences for a neutral object as compared to shaking one's head (Tom et al., 1991). A study by Förster and Strack (1996) documented that when participants are instructed to nod their heads, they are better at recognizing positive words, whereas those who are instructed to shake their heads are

better at recognizing negative words. These data indicate that the congruence of head movement with the valence of words was seemingly crucial for recognition memory of the words.

Feedback from Other Forms of Sensorimotor Manipulation

Finally, studies have also indicated that feedback from proprioceptive sensations, such as temperature, weight, and texture, can affect human thought and judgment. For example, Williams and Bargh (2008) showed that when participants were instructed to hold a hot cup of coffee, they tended to perceive others as warmer (e.g., more friendly and welcoming) than when they were instructed to hold an iced coffee when making such judgments.

Brief Evaluation of the Embodiment Research on Body Manipulation

Although the accumulated evidence supports embodiment effects, a note of caution is due when interpreting the findings. First, the effects of different body manipulations have not been equally tested and replicated and the effect sizes for those that have been extensively studied have been heterogeneous and often ranged from moderate to small. Next, there is much that remains to be learned about the underlying etiological mechanisms and limiting conditions for the effects. Of these limiting conditions, the degree of congruence or incongruence of body response and context may be especially important. For example, there is evidence that suggests that a contractive, depressive posture has deleterious effects after success (Riskind, 1984) but positive anti-depressant effects after failure or social exclusion (Welker et al., 2013. As Elkjaer et al., (2020, p. 25) have pointed out, “In this congruency view, it would not be beneficial to adopt a simple so-called power pose (cf., Cuddy et al., 2015) when feeling upset.” Similar congruence effects are suggested by studies of head nodding or shaking or drawing positively or negatively valenced stimuli closer versus pushing them away (Briñol & Petty, 2003; Cervera-Torres et al., 2019).

Notwithstanding the limitations, such research has suggested the potential importance of considering manipulations of body states in

clinical interventions. Moreover, the impact of manipulations of body states is in accord with findings from the clinical realm that indicate that relaxation training can reduce feelings of anxiety (Manzoni et al., 2008).

Embodiment in Clinical Disorders

It has repeatedly been observed that individuals who struggle with depression, anxiety, schizophrenia, or other types of disorders exhibit different patterns of posture, gait, and movement, as well as patterns of sensorimotor and anomalous perceptual experiences. Combined with the theories and research we have reviewed, these observations strongly suggest that these different body patterns and movement may play roles that contribute to clinical disorders. In line with this idea, theorists and researchers have suggested that these different experiences of body postures and movement can shape and influence how individuals appraise or construe and react to themselves and the world.

Big Picture Perspectives

Before we review specific formulations for clinical disorders, we should note that Fuchs and Schlimme (2009) have offered a phenomenologically based classification for distinguishing the ways in which different embodiment anomalies can influence and distinguish different clinical disorders. As shown in Fig. 22.1, they used the term ***hyper-embodiment*** disorders to denote disorders in which individuals' mental states and perceptions of the self and world are dysregulated because they are excessively colored or over-weighted by their experiences within the physical boundaries of their bodies. A major example is clinical depression, which as we will see below, may involve the inordinate influence of body states such as heaviness and slowness on the depressed individual's outlook and experience of the world.

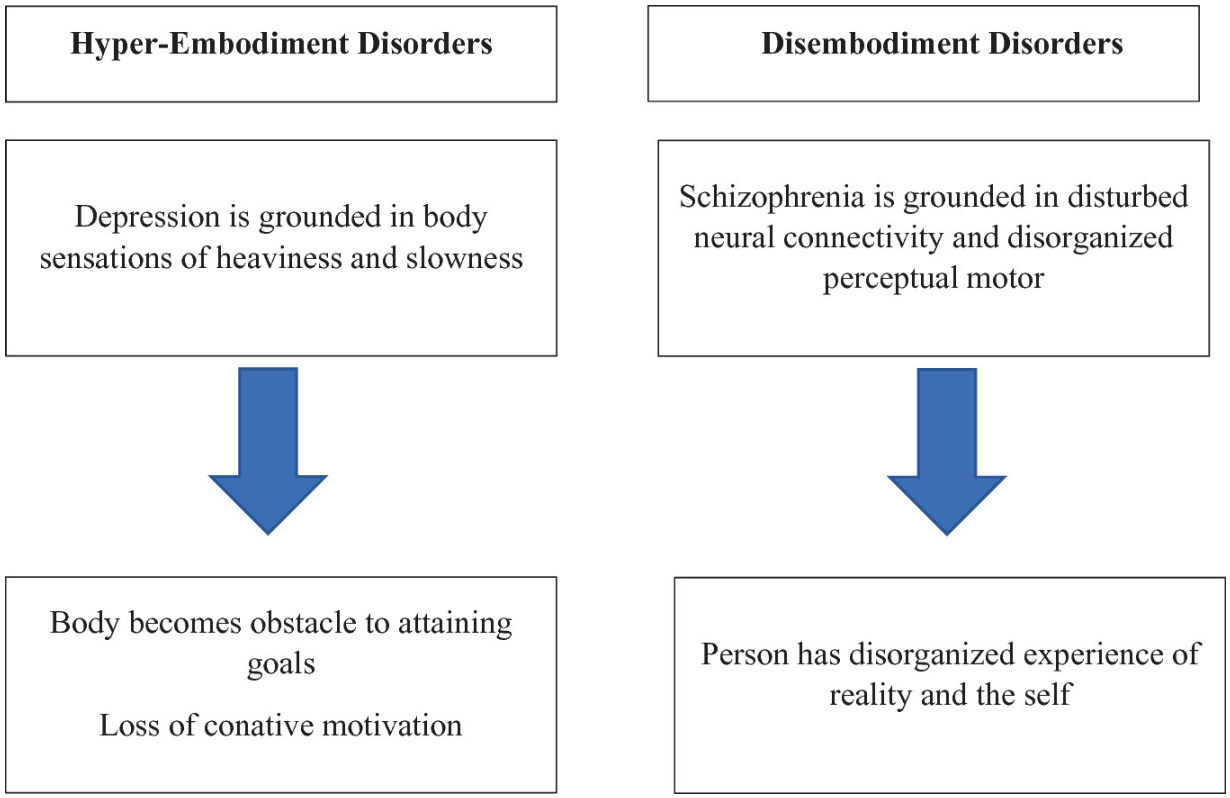


Fig. 22.1 Fuchs and Schlimme's (2009) scheme

Next, Fuchs and Schlimme (2009) suggest that embodiment anomalies can influence disorders in a second way through more fundamental disturbances involving basic neural connectivity. They refer to this group of disorders which include schizophrenia as ***disembodiment disorders.*** In these, impairments at a basic neural level act to impair individuals' abilities to form a coherent sense of self and the world; the "embodied self" is disorganized and chaotic. Moreover, Fuchs and Schlimme (2009) distinguish such disorders of the "self" where the sense of self is disturbed by disembodiment anomalies, from disorders of "self-image," such as eating disorders.

In Fig. 22.2, we offer the term of ***experiential avoidance*** disorders as an alternative interpretation (or reinterpretation) of Fuchs and Schlimme's (2009) label of "hyper-embodiment disorders." Our reinterpretation helps to underscore the important role of avoidance of inner experience (sensory, affective, or cognitive), since research has identified this as a pervasive theme and an etiologically important contributor to many disorders (e.g., depression, anxiety, PTSD, and eating disorders). Experiential avoidance refers to defensive

psychological responding that people engage in to buffer or detach themselves from painful feelings or realities. Such defensive responsding frequently involve the use of repetitive language-based thought processing to avoid more concrete felt emotions and painful feelings and physical sensations. It should be emphasized here that we do not deny the feedback effects of bodily states such as heaviness or slowness on thought processes and cognitive appraisals; rather, our intention is to bring out a different aspect of embodiment problems that Fuchs and Schlimme (2009) overlooked or have not addressed.

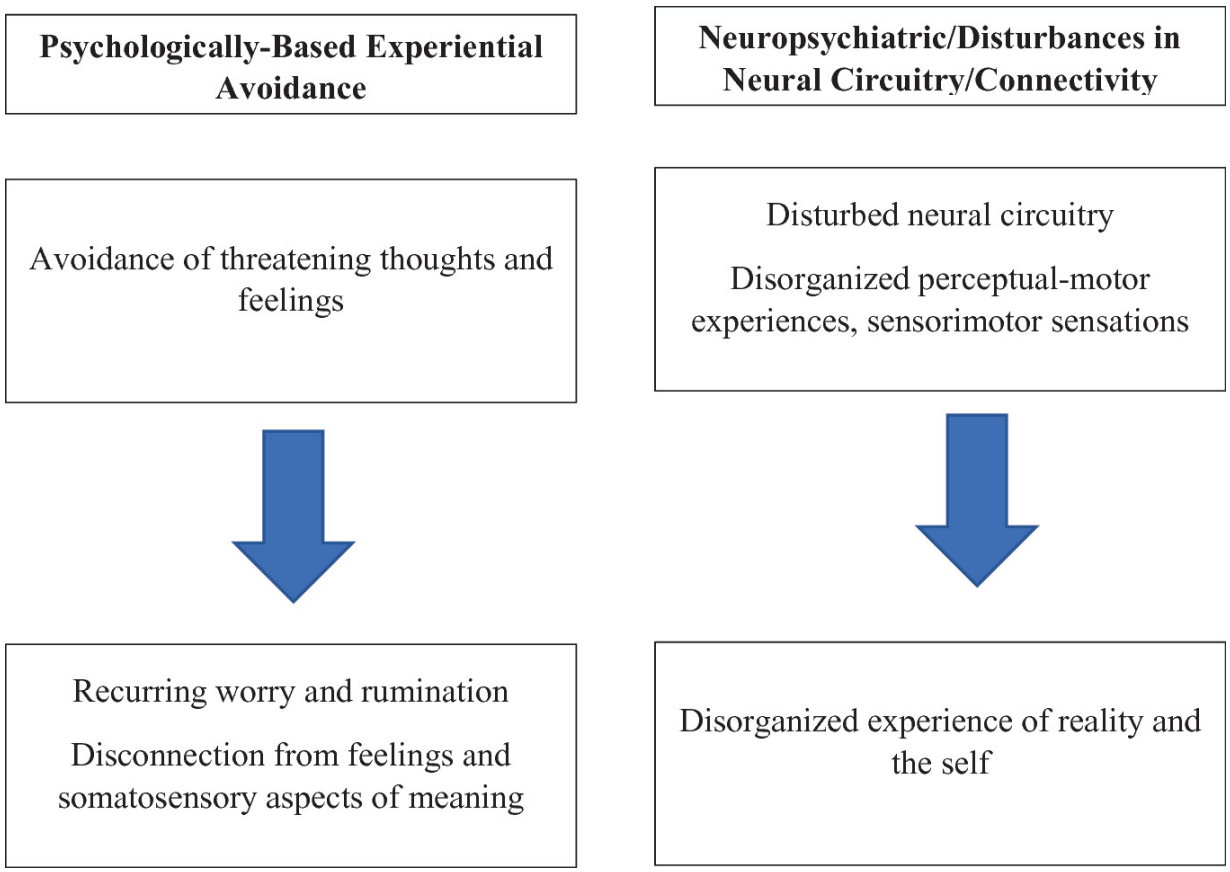


Fig. 22.2 Alternate scheme

Finally, in accord with Fuchs and Schlimme (2009), some disorders (e.g., schizophrenia) derive from more fundamental disturbances in neural circuitry and connectivity. In Fig. 22.2, we label these as neural "circuitry/connectivity" disorders.

Disorder-Specific Embodiment Conceptualizations

In the remaining sections in this chapter, our goal is to briefly review embodiment conceptualizations that have been formulated to increase understanding of several disorders. We will conclude by considering embodiment interventions and their potential inclusion in CBT treatments.

Depression. Clinical depression, and particularly when it presents in its most serious form of major depressive disorder, is characterized by exaggerated feelings of sadness, hopelessness, and worthlessness, as well as loss of interest, motivation, and enjoyment, and somatic symptoms such as loss of appetite, ability to concentrate, and fatigue and sleep difficulties.

Cognitive models have sought to explain depression in terms of the negative thoughts, negative beliefs, expectations, misappraisals, and causal attributions of depressed individuals (e.g., Clark & Beck, 1999) that produce feelings of helplessness and hopelessness (Abramson et al., 1989). Lindeman and Abramson (2008) proposed a theoretical elaboration of Abramson and colleagues' (1989) hopelessness model of depression to elaborate the role of embodiment. In their formulation, the perception of powerlessness or the inability to alter events (a key construct in the hopelessness model) that can induce depression is grounded or embodied in the experience of "motor incapacity." When one is depressed, one's feelings of powerlessness as well as one's hopelessness cognitions are simulated or re-enacted with experiences of physical states of low energy, lethargy, slow motor movement, and delays in initiating movement. Lindeman and Abramson (2008, p. 241) stated that "if one cannot ***feel*** hopeless about a situation, one should find it exceedingly difficult to ***believe*** that the situation is hopeless." On the other hand, they suggest that if one experiences bodily sensations of power, this might "encourage beliefs that the situation is somehow amenable to change."

It is recalled that Fuchs and Schlimme (2009) assumed that when individuals are suffering from severe depression, their embodiment experiences of the self and world are colored and molded by their physical feelings of heaviness, weakness, and slowness of the body. Their feelings of physical heaviness and weakness, along with their tendencies to walk slowly, with altered gait patterns, and postures create obstacles to their ability to attain goals, rather than giving them

access to the world. Furthermore, their loss of interest and enjoyment and an "appetitive," or conative dimension to their experience, lessens their ability to imagine future positive events or prompt goal striving. In brief, both Fuchs and Schlimme (2009) and Linderman and Abramson (2008) view the depressed person's feelings of a heavy, slow body, slow gait, etc., in depression as not just a result of, but as actively impacting, the depressed person's feelings of impediments to goal attainment.

Consistent with these two embodiment perspectives, there is evidence that people who struggle with depression tend to adopt slumped body postures and move with a distinctive gait. They walk more slowly while showing smaller arm swings than people who are not depressed. In addition, they show greater side-to-side lateral sway of the body, and reduced vertical up and down body movement (Michalak et al., 2009). Michalak et al. (2012) refer interested readers to an animation illustrating such phenomena at http://biomotionlab.ca/Demos/BMLdepression.html.

There is also evidence suggesting that modifications of posture and movement can be employed, at least in some circumstances, to improve depressive symptoms. For example, a study by Wilkes and colleagues (2017) on individuals presenting with depression compared the effects of their usual posture (which was typically stooped) or upright posture on affect and reported feelings of fatigue. They showed that when depressed participants were instructed to adopt an upright posture manipulation, they reported higher arousal, more positive affect (e.g., excited, strong), and less fatigue compared to when they were in their usual postures. In addition, it was found that an upright shoulder angle was associated with lower negative affect and anxiety in both posture conditions (Wilkes et al., 2017).

Gjelsvik and colleagues (2018) emphasize a "top-down" dysregulation process that arises from rumination and defensive experiential avoidance (Gjelsvik et al., 2018). A great deal of prior research supports the idea that depression is associated with over-abstract and over-general memories and with ruminative thinking (abstract, language based thinking and brooding about "why" negative events occur, and "what" their consequences will be) (Watkins, 2008). According to Gjelsvik et al. (2018), such over-abstract thinking leads

individuals to avoid remembering specific concrete painful memories and truncates physical and affective experiences. Moreover, depressed individuals frequently ruminate in broad abstract terms about the causes and consequences of their own depression (e.g., "Why am I depressed?"). The downside of this experiential avoidance is that depressed individuals cannot identify ways to address specific social problems (Watkins, 2008; Watkins & Moulds, 2005) or reduce discrepancies between their present states and desired states because they view their problems in overly abstract and general terms. Such over-abstract or over-general thinking can lead to a worsening and prolonging of clinical depression.

Anxiety. Anxiety disorders are a category of disorders represented by exaggerations of various symptoms such as anxiety, worry, and fear that are disproportionate in degree and/or duration. Such disorders, including generalized anxiety disorder, panic, and phobias, are characterized by exaggerated threat perception and hypervigilance, worry, and avoidance, as well as by physical symptoms such as heightened physical tension and rapid heartbeat.

Several contemporary CBT models have included embodiment components. Lang's (1979) bio-informational model of fear structure and emotional imagery in anxiety and phobias was a seminal embodiment approach to anxiety disorders (see also Ji et al., 2016). By his important account, phobias—such as irrational fears of snakes or spiders—are rooted in an associative fear structure (or network) that links the phobic individual's fear-related bodily responses to the person's emotional images of phobic stimuli (e.g., eye movements following the sinuous movements of snakes, rapid heartbeats) and perceptual characteristics of phobic stimuli (e.g., the color, size, and movement of snakes) and to semantic meaning (e.g., danger). Numerous studies have supported Lang's proposal that for a full activation of a phobic fear reaction, there must be a corresponding full activation of the embodied elements of the emotional imagery in the fear structure.

Borkovec's influential model of worry (e.g., Borkovec et al., 2004) is one of the earliest contemporary CBT accounts to emphasize the central role of experiential avoidance in clinical disorders. By his account, worry is a largely verbal-linguistic activity that is reinforced

by the short-term relief it provides anxious individuals by helping them to avoid the concrete imagery and sensory feelings of fear. It has been shown that worry is a primarily language-based activity that is focused on abstract linguistic and symbolic representations of threatening concerns. Following Borkovec's formulation, other models have suggested that worry facilitates the experiential avoidance of negative affect more generally (Roemer & Orsillo, 2007) as well as sudden and unexpected shifts that intensify such affective reactions (Newman et al., 2014).

Another contemporary model with embodiment features—the looming vulnerability model (Riskind & Rector, 2018; Riskind et al., 2000)—was formulated as an embodied refinement of cognitive models (Beck et al., 1985; Clark & Beck, 2010), which assume that faulty threat appraisal plays a central etiological role in anxiety. But unlike such cognitive models, which operationalize threat appraisal in terms of static disembodied expectancies of the probability and cost of negative events, the looming vulnerability model emphasizes more embodied, perceived mental simulations of dynamically emergent potential threats. Specifically, the "looming" model holds that threat perception in anxious individuals is embodied in perceptions of mental simulations (or re-enactments) of threatened events as rapidly growing and approaching them as they expand in their urgency and potential negative consequences. As one example, individuals who fear spiders, contaminants, or other threats (e.g., health problems or social rejection) express these threats in terms of spontaneous mental simulations of these threats (even when shown in static photos) as rapidly moving, growing, and approaching (for an extensive review, see Riskind & Rector, 2018).

Posttraumatic Stress Disorder (PTSD). PTSD is a clinically significant disorder that develops during or later after an individual's direct exposure or witnessing of traumatic life-threatening events (e.g., combat, death, rape, fires, accidents). The most outstanding symptoms of PTSD include the re-experiencing of the traumas through nightmares and/or flashbacks, emotional numbing, avoidance of behaviors or places associated with the trauma, and heightened arousal in the form of difficulties in concentration, sleeping, and jumpiness. It has been documented that individuals with PTSD exhibit

experiential avoidance that takes the form of pronounced dissociative experiences, such as experiencing things in dreamlike ways as if they were unreal, feeling as if one's mind is in a fog, or watching oneself as if one is a spectator and feeling disconnected from one's body. Such dissociation from the reality of current situations might be seen as an extreme form of experiential avoidance that involves detaching oneself from the embodied experience of the terror of traumatic events. Physical avoidance of situations that remind one of traumas can have the same function, as may the fractured nature of traumatic memories in PTSD, which may dissociate somatosensory experiences from the signi cance of the relevant events.

A recent therapeutic approach referred to as Multimodular Motion-assisted Desensitization and Reprocessing (3MDR: Vermetten et al., 2013) attempts to address such avoidance problems. It incorporates walking on a treadmill toward salient photographs depicting past traumatic events (e.g., military deployment). From an embodied perspective, physically walking toward such traumatic reminders represents an approach behavior as opposed to the desire to engage in avoidance (Nijdam & Vermetten, 2018). Nijdam and Vermetten (2018) have hypothesized that approaching these events, both cognitively and physically, may enhance the patient's self-e cacy, self-re ection, and emotional engagement, thereby leading to better therapeutic outcomes.

Eating Disorders. Eating disorders such as anorexia or bulimia pose signi cant health problems and are highly prevalent. Anorexia nervosa is a clinical disorder characterized by symptoms involving severe restriction of food intake, which leads to low body weight, intense fear of weight gain, along with disturbance in the way one's weight or shape is experienced. Bulimia nervosa involves symptoms involving recurrent episodes of binge eating, frequent compensatory behaviors (e.g., vomiting, laxative use), and an exaggerated perception of body shape and weight having impact on self-evaluation.

By one embodiment account, individuals who have eating disorders may experience "a profound dislike" toward their bodies and body-based experiences (McBride & Kwee, 2018). This dislike and alienation from their bodies, in turn, is construed as leading to a profound experiential avoidance that takes the form of divorcing oneself from

the body and its experiences. It is thought that such detachment from the body can lead to a cascade of negative consequences involving emotional numbing, a limited capacity for emotion, and impairment in feelings of connection with others. Consistent with such an account, it has been shown that patients with anorexia nervosa exhibit signi cant impairments in their awareness of their bodies and dif culties in describing their body experiences (Kolnes, 2012).

Schizophrenia. Schizophrenia denotes a larger category of psychotic disorders that involve symptoms such as hallucinations and delusions, odd speech and language, and disturbances in affect, movement and posture. As Fuchs and Schlimme (2009) noted, schizophrenia seems to be rooted in fundamental embodiment problems involving anomalies in neural circuitry that disrupt the ability of the individual with schizophrenia to make coherent sense of themselves and the world. Martin and colleagues (Martin et al., 2016) have elaborated this view and proposed that schizophrenia involves a fundamental "disembodiment" of the sense of self-caused by impairments in neural activity (also see Röhricht & Priebe, 2006). Due to this disembodiment, individuals with schizophrenia experience mental states that are fractured and incoherent. Thus, schizophrenia may arise "bottom-up" from the fragmentation of the perceptual experience of the self and reality, and fundamental de cits in "bodily-mediated" consciousness, rather than from higher-level cognitive processes such as faulty "theories of mind." Such a fragmentation of one's experience can result in a "hollowed out" and disorganized sense of self and a disjointed sense of the world. Such problems, in turn, negatively impact the ability of individuals with schizophrenia to relate to others.

In this context, a recent randomized controlled trial reported by Martin and colleagues (2016) found that patients with schizophrenia who received a movement therapy intervention based on Body Psychotherapy and Dance Movement Therapy had signi cantly lower negative symptom scores (e.g., blunted emotional responses, withdrawal, blunted affect, attention) than those in a waitlist control group. A prior study by Röhricht and Priebe (2006) found similar results with patients receiving a movement therapy intervention

compared to those receiving supporting counseling sessions devoid of the movement element.

Autism Spectrum Disorder. Autism spectrum disorder is a lifelong neurodevelopmental disorder, much like schizophrenia, that may derive from a fundamental disturbance in neural function. It involves numerous symptoms including pervasive difficulties with verbal language and interpersonal communication and interaction. De Jaegher (2013) has suggested that the sense-making of self and world in individuals with autism is centered in the experience of peculiar patterns of attention, movement, and action. These produce a disturbance in the embodied sense of self. Thus, like schizophrenia, autism may primarily result from impairments in lower-order processes rather than from higher-order dysfunction such as in one's theory of mind (Frith & Baron-Cohen, 1987). A few studies testing body-based movement therapies have examined whether these are beneficial for autism. However, the results are inconclusive because only a few used randomized controlled trials and their sample sizes were small (Hourston & Atchley, 2017).

The Application of Embodiment Interventions in Psychotherapy

Weineck and Messner (2018) have defined embodiment interventions as therapeutic methods that use "the body itself (e.g., by moving the body in space or adopting a particular posture) or sensations arising from it, as a valuable resource for self-awareness and therapeutic change" (p. 122). Along the same lines, Heller (2012) proposed "body psychotherapy" (BPT) as a term to refer to psychotherapies that directly utilize body techniques. Definitions of embodiment interventions often suggest that increasing embodied self-awareness may help individuals to get into better contact with their emotional experiences (Tantia, 2016). Recently, Pietrzak and colleagues (2018) have emphasized that embodiment interventions may require the selection of different strategies for different disorders (Pietrzak et al., 2018).

Contemporary Efforts to Develop a More Embodied Cognitive-Behavior Therapy

Given the signi cant percentage of patients who have suboptimal treatment responses to CBT, an increasing number of calls are being made to draw on affect-based interventions and embodiment methods (Gjelsvik et al., 2018; Pietrzak et al., 2018). The importance of affective experience is supported by studies showing that the intensity of emotion activated during CBT interventions is related to the successful achievement of positive therapeutic outcomes (Aa jes-van Doorn & Barber, 2017).

Pietrzak and colleagues (2018) have proposed an integrated "switch model" (see Fig. 22.3) that brings together CBT and affect (and embodied) based approaches to psychotherapy. Bringing these together, Pietrzak and colleagues' (2018) framework uses a CBT systematic case formulation approach to identify problems, factors that contribute to the onset and maintenance of the problems, and to their dif culty in resolving them. Clients are taught mindful awareness practices including how to scan and observe discrete body sensations accompanying their emotions. The switch model uses the CBT technique of asking clients to think of a key person and situation where they felt the highest emotion. This involves the induction of affect by visualization of an event where they experienced the most intense emotion. The psychotherapy then switches to an embodiment approach in which clients move to more sensory-perceptual modes of cognition in which they use mindfulness practices to track their somatic symptoms and affect in response to the person and situation. A goal of the switch model is to promote cognitive restructuring as well as increase clients' acceptance of their emotions and their meta-cognitive understanding of the emotions.

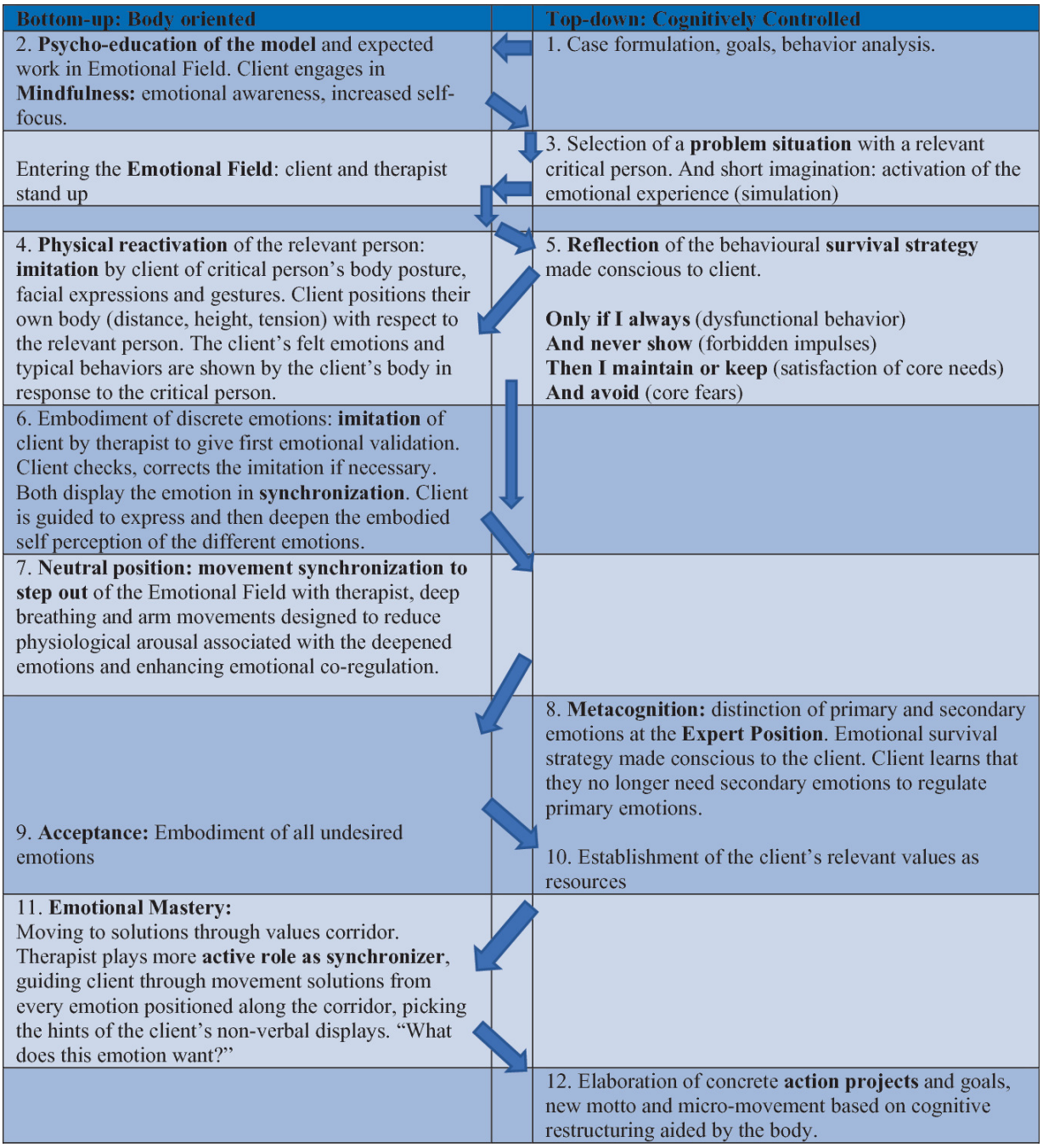


Fig. 22.3 Overview of the switch between top-down and bottom-up orientations. Adapted from Pietrzak et al. (2018)

Mindfulness Based Cognitive Therapy (MBCT; Segal et al., 2002; Teasdale et al., 2000) has been empirically supported for more than two decades as a form of CBT that incorporates mindfulness training and practice (Kabat-Zinn, 2003). MBCT can be used to augment treatment for patients with three or more prior depressive episodes.

Mindfulness is used to increase the nonjudgmental awareness of depressed patients of their bodies and their emotional experiences. MBCT assumes that mindfulness training can help in disrupting a link between negative affect and negative ruminative thought activity that characterizes and exacerbates depression. MBCT is assumed to work because it can help depressed patients to better recognize and disengage from perseverative language-based ruminative negative thought patterns. Several studies have found that MBCT reduces relapse rates among individuals who have suffered from three or more major depressive episodes (Ma & Teasdale, 2004; Teasdale et al., 2000).

Along with mindfulness training and affect-based approaches, other body psychotherapy approaches and interventions may show promise in enhancing CBT. For example, Dance Movement Therapy has been documented by a meta-analysis to improve quality of life and reduce anxiety and depressive symptoms (Acolin, 2016; Koch et al., 2014). Another meta-analysis suggests that Tai Chi and Qigong, approaches derived from Eastern traditions, can help in the prevention and management of anxiety and mood disorders associated with medical conditions (Osypiuk et al., 2018). For other examples, Gestalt Therapy (Perls, 1973) uses the exaggeration of expressive behaviors such as the "empty chair" and exaggeration techniques, and these may be useful in certain situations. Furthermore, embodiment elements from Dialectical Behavior Therapy (DBT; Linehan, 1993a), a special form of CBT to increase distress tolerance and control over impulses, might also be useful. The "willing hands" technique teaches clients to hold their hands upturned and unclenched, face their palms upwards, and relax their fingers in order to signify openness to accepting reality and experience. They are the antithesis of clenched hands, which are often the opposite of accepting these and indicative of anger (Linehan, 1993b).

Incorporating Empirically Supported Body Manipulations

In addition to the above, CBT could potentially incorporate empirically supported embodiment manipulations (e.g., postures, facial expressions, gait) to improve CBT outcomes. A good example of this idea is provided by a recent study by Peper and colleagues (2019), who examined the impact of combining a cognitive reframing technique

(through language) for stressful memories and a body-oriented technique (instructing them to sit in an erect, upright versus a normal posture). Their intriguing results indicated that cognitive reframing was more effective in reducing negative thoughts, anxiety, and tension when paired with a change in posture than when reframing was done with language alone (Peper et al., 2019).

As we previously saw, a forward lean has been linked to thinking about the future as opposed to the past (Miles et al., 2010) as well as a greater openness to accepting new ideas and advice (Shirasuna et al., 2019). It is plausible that patients' receptiveness to treatment and treatment recommendations might be increased by instructing patients to adopt a forward body lean (or at least not to adopt a backward lean), perhaps in combination with the "willing hands" technique of DBT of holding palms open to indicate receptiveness. Likewise, targeting patients' willingness to make therapeutic changes and process recommendations nondefensively might be enhanced by altering eye gaze behavior or other avoidance behaviors (e.g., postures).

Other empirically supported body movements that might be employed therapeutically include head nodding or shaking or other various approaches and avoidance movements. For example, Vermetten and colleagues (2013) sought to reduce experiential avoidance of trauma stimuli by instructing individuals to walk on a treadmill toward pictures of such stimuli. By the same token, it could be useful to have patients with eating disorders or distorted body images to make approach-oriented body movements (e.g., on a treadmill) toward personally aversive pictures of their own faces and bodies, or pulling these images closer with arm movements. Head nodding or shaking may also have potential applications such as strengthening or weakening con□idence in thoughts (Briñol & Petty, 2003) and preferences for desirable or undesirable behaviors (Tom et al., 1991).

Modi□ication of the congruence or incongruence of patients' body postures and movements and gestures with their thoughts, mental states or context may sometimes be helpful. Jo and Berkowitz (as cited in Berkowitz, 2000) reported that instructing patients to clench their □ists, versus having a relaxed □ist, increased their feelings of anger and

presumably their anger-related cognitions when remembering anger-inducing events. Interestingly, fist clenching proved to have the reverse effect when participants recounted sad memories and reduced their feelings of sadness. In combination with studies such as Schubert (2004), it seems possible that fist clenching (and perhaps other bodily responses such as expansive postures) may help to counter feelings of sadness and helplessness by embodying feelings of power and control. Furthermore, modification of the congruence or incongruence of bodily responses could be useful for demonstrating that bodies influence thoughts and feelings; this could help show patients that it may be useful for them to self-monitor and keep track of their bodily states.

In addition to the above, some interesting data suggest that instructions to modify body posture and motoric behavior may have treatment implications for recovery from negative mood states. Specifically, Veenstra et al. (2017) found that when participants with depression were put into a negative mood induction condition, those who were instructed to adopt a stooped posture condition reported larger increases in negative mood than those who were instructed to adopt an upright posture condition.

Intriguing data were reported in a study by Koch and colleagues (2007) which assigned thirty-one currently depressed patients to one of three different conditions: (1) a dance condition, entailing an upbeat circle dance with up and down movements for 20–30 min, or (2) a passive condition, in which they listened to music without dancing, or (3) another control condition in which they exercised on a stationary bicycle at the same arousal level as the dance group. Their data showed that participants' depression levels were most decreased, and their vitality levels increased, in the dance condition. Thus, the up and down dance movement appeared to be crucial. Mere arousal increases appeared to have had little anti-depressive effect (Koch et al., 2007).

Manipulations for Embodiment That Do Not Directly Manipulate Patient's Body Movements

Some empirical findings indicate that embodiment anomalies may possibly be treated, at least in part, with CBT methods, and not just by "bodywork" manipulations. Gjelsvik and colleagues (2018) have

reviewed evidence that supports that training depressed individuals to think in more concrete, specific, and sensory-perceptual rich, rather than over-general, terms help to reduce their tendencies to ruminate and be depressed (Neshat-Doost et al., 2013; Raes et al., 2009; Watkins et al., 2012). Thus, CBT methods that attempt to reduce over-abstract language-based problem representations may help individuals to be in better touch with the necessary embodied grounding for more effective problem solving and better mood.

As it happens, several open pharmacological trials and a randomized controlled trial have also provided preliminary evidence that injections with Botulinum toxin (from which Botox is made) into the frowning (corrugator) muscle of the face may help in reducing depression (Finzi & Rosenthal, 2014). According to these investigators, Botulinum may reduce amygdala response by suppressing proprioceptive feedback from corrugator responses to emotional stimuli.

Finally, research on nonverbal synchrony could imply that when a clinician's body language is synchronous with a patient's body language and mirrors their body positions and movement, this may be beneficial for the psychotherapeutic relationship and therapy outcomes (Ramseyer & Tschacher, 2011). However, a note of caution is needed for this direction of research is still limited.

Limitations

Despite the potential promise that they may afford, there is a paucity of evidence that supports that adding embodiment elements to CBT will improve treatment outcomes. Furthermore, a recent review by Röhricht (2009) concludes that while there is a plethora of body-oriented approaches (see Fig. 22.4), empirical support has been found for only a handful of these (e.g., functional relaxation, Dance Movement Therapy). Another word of caution, as suggested by Pietrzak and colleagues (2018), is that the selection of embodiment interventions should optimally be matched to the psychological anomalies associated with specific disorders.

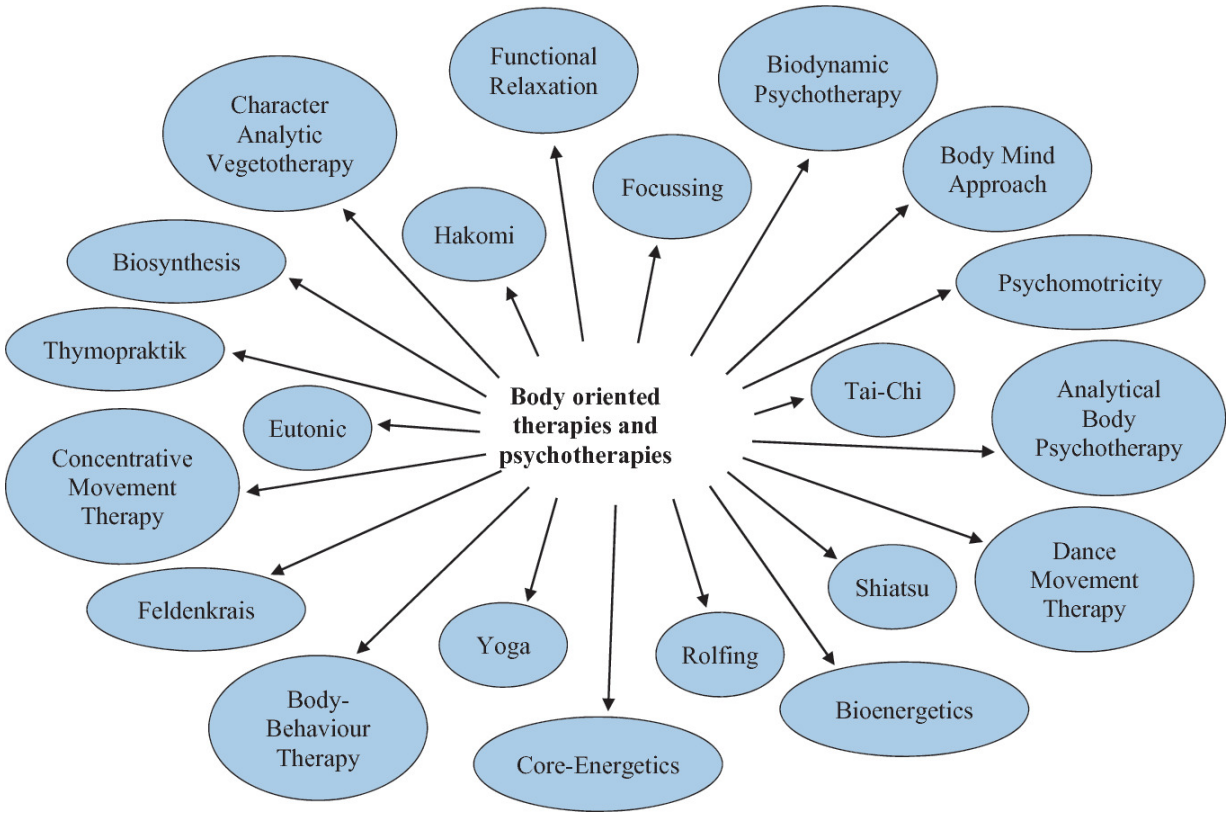


Fig. 22.4 Different body-oriented psychotherapy and body therapy schools. Adapted from Rohricht (2009)

A further caveat is that embodied elements should probably not be haphazardly or randomly merged with CBT treatment. Alford and Beck (1997) have discussed that while methods and/or concepts can be incorporated into CBT from other approaches and literatures, they should have clear theory-guided rationales and empirical grounding. To take an example, in accordance with the literature that has accumulated, there may be grounds for incorporating the targeting of depressive postures and gait patterns in CBT, since these may embody and reinforce feelings of powerlessness and hopelessness among depressed individuals.

Conclusions and Recommendations

MBCT provides an important contemporary precedent for incorporating embodiment elements into a CBT. Another example is provided by Wolpe's (1958) earlier pioneering behavioral technique of

systematic desensitization. The premise of the concept of “reciprocal inhibition” ` in systematic desensitization is that instructing anxious or frightened individuals in the use of physical relaxation skills could reduce their fear because states of relaxation are incompatible with the physical tension and other symptoms that are intrinsic to anxiety. Whatever such promising precedents, a good deal more research is clearly needed to establish whether embodiment interventions can improve CBT and its outcomes for different clinical disorders.

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Part IV
Current Issues and Future Directions

© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_23

23. Mechanisms of Embodied Learning Through Gestures and Actions: Lessons from Development

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Abstract
The body plays a central role in learning across the lifespan. Looking at embodiment through the lens of human development can therefore help us recognize important patterns and consistencies across time and contexts that may otherwise go unnoticed. This chapter takes an in-depth look at gesture, a type of representational action that is particularly prevalent in learning and educational settings. Throughout the chapter, we also contrast hand gestures with other types of actions —goal-directed actions and demonstration actions—to help elucidate the features of bodily movement that are most likely to lead to the acquisition of new conceptual knowledge. We argue that gestures, and some demonstration actions, serve a unique role in learning across childhood precisely because they bridge the gap between body and mind. Gestures are produced by the body but, unlike goal-directed actions, are necessarily produced along with spoken language and must be integrated with that language. Moreover, gestures have a

representational capacity that goes beyond the immediate context to promote learning and conceptual development.

Keywords Gesture – Action – Demonstration – Embodiment – Learning – Development – Infant – Child – Mathematics – Mechanisms – Conceptual development

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The goal of this chapter is to explore the ways in which children acquire new ideas through their own actions and through the actions of others. This idea, that conceptual change can come about through direct interaction and engagement with the physical environment, is not new, nor is it unique to embodiment theories. Early twentieth-century philosophers and educators such as John Dewey and Maria Montessori formally popularized the notion that human knowledge comes from interactions with the external environment. In his book, ***Democracy and Education***, first published in 1916, John Dewey wrote, "If knowledge comes from the impressions made upon us by natural objects, it is impossible to procure knowledge without the use of objects which impress the mind" (Dewey, 1916). Montessori was also a firm believer that true learning comes not from verbal instruction by someone more knowledgeable but through a child's own active exploration of their environment (Montessori, 1909, 1995). She started an educational movement, still popular today, in which a child, provided with the right objects, can discover for herself such high-level concepts as the Pythagorean theorem through physical play and guided exploration.

Jean Piaget was a prolific writer, scientist, and theoretical thinker, who was also arguably the founder of the field of developmental psychology. He echoed the sentiments of both Dewey and Montessori in many of his works on how children acquire new knowledge, arguing that physical actions on external objects, when combined across time, "constitute the base of knowledge" (Piaget, 1972) and that children learn best when they begin with more concrete representations of an idea before moving onto symbolic ones (Piaget, 1951, 1953). By way of illustration, Piaget tells an anecdote about a small boy who counts a row of pebbles, rearranges them into a different shape, counts them

again, and is delighted to find that he gets the same number (Piaget, 1972). In this example, neither counting the pebbles, nor rearranging the pebbles, is the ultimate educational goal of the action, but rather, these actions allow the child to discover a broader principle about conservation of number.

These great thinkers highlight the ways in which active play can lead to great conceptual insight, and underscore the importance of shaping children's physical environment to set them up for success. Yet it is inarguably the case that a child may play with pebbles many times without discovering the principle of conservation of number. In her review of the Montessori method of instruction, Angeline Lillard underscores the importance of both structure and explicit teacher (or peer) demonstrations to help align children's "movement and cognition" while they are using carefully designed physical materials to learn a new concept (Lillard, 2016). Indeed, it is the goal of many parents, and certainly of teachers in our current educational system, to facilitate or scaffold the process of knowledge acquisition by using a combination of direct instruction via language and an arsenal of action-based tools, including well-designed manipulatives with a small, intentional set of affordances; demonstration actions; and communicative hand gestures.

This chapter synthesizes our current understanding of when and, most crucially, ***how*** children learn new ideas or concepts from the kinds of actions that are particularly common for teachers and/or children to produce in learning and instructional settings—hand gestures, demonstration actions, and goal-directed actions. In so doing, we hope to highlight the ways in which a mechanistic understanding of body-environment interactions across development can contribute to modern embodiment theories. More specifically, we argue that hand gestures, and some types of action demonstrations, play an important role in embodiment theory precisely because they are representational tools that bridge the gap between the mind, language, and the external environment to help create new conceptual knowledge across development.

Defining Movements in Instructional Contexts

Broadly construed, the word “action” can refer to any movement performed by an agent. But for the purposes of this chapter, we are choosing to distinguish between three subcategories of action that is commonly used by teachers or learners in educational and instruction settings: gestures, goal-directed actions, and demonstration actions. Gestures are empty-handed movements that do not interact directly with external objects and make no lasting changes upon the environment. For example, an infant pointing to her cat to represent “that [cat]”; a child holding up three fingers to represent “three”; or a teacher simultaneously tracing two sides of a math equation to represent “equal sides”. While gestures have been described and categorized by scholars into several broad, descriptive classes (e.g., Kendon, 1980; McNeill, 1992), here we focus primarily on representational gestures and deictic gestures, as they are common in learning contexts.

Deictic gestures are used to identify a spatial location or specific referent in the environment, usually through pointing. Representational gestures include iconic gestures, which convey information through the similarity of their form and their referent, and metaphoric gestures, which represent ideas through a metaphoric relation between the gesture form and its abstract meaning (see Fig. 23.1 for examples). Broadly speaking, representational gestures are used symbolically to depict something else. This representational property of gesture gives it both power in representing abstract concepts, and provides challenges for some learners with insufficient content knowledge (e.g., Congdon et al., 2019; Novack et al., 2014). Both of these ideas will be discussed later in the chapter.

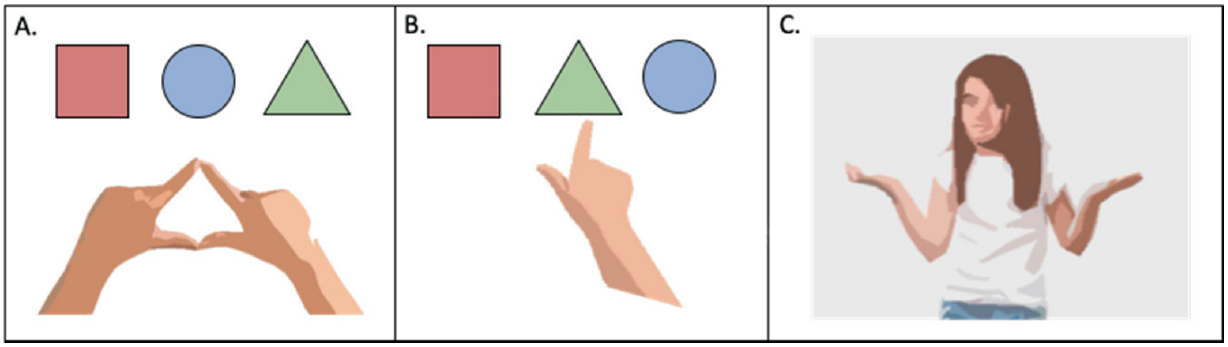


Fig. 23.1 If a child were asked which of three shapes was a triangle, Panel A shows a possible iconic gesture response, where the child’s fingers create a triangular shape. Panel B shows a

deictic gesture response where the child is indicating "that [shape]" by pointing to the shape in the environment. Panel C shows a possible metaphorical response where the child is making a palm up gesture that represents an "emptiness" or absence of knowledge (Cooperrider et al., 2018; Parrill, 2008)

To understand more about how gestures function, it can be useful to compare them with goal-directed actions, which are movements that interact with and change the external environment. They involve a direct object that is acted upon, but they are ***not*** representational or symbolic. Examples of goal-directed actions include an infant grabbing a toy, an elementary school child stacking blocks, or a teacher organizing papers on her desk. In an instructional setting, a child may perform a goal-directed action because she was told to move objects in a certain way—the goal, in this instance, is to mimic the actions of the instructor.

Furthermore, we argue that these goal-directed actions should be distinguished from action demonstrations, in which the actor, usually a teacher or parent, is performing an action with the explicit intent of representing or depicting a concept (see Clark, 2016, for a review of how depictions, including in the form of iconic gestures or representational action demonstrations, are an integral part of communication). As a simple example, picture someone twisting a lid off of a jar. In this case, the goal-directed action that the person is performing is twisting the lid off of the jar to remove it. If this person were performing an action demonstration, she might twist off the lid, put it back, and then hand the jar to a child, with the goal of ***demonstrating*** to the child ***how to twist*** [off the lid]. A gesture that mimes a twisting motion above the jar without ever touching it would also have the purpose of demonstrating ***how to twist*** [off the lid]. Notably, goal-directed actions and demonstration actions share form, but demonstration actions and gestures share function.

This framework places action demonstrations in the middle of a Venn Diagram linking goal-directed actions, which are not representational, and gestures, which have the flexibility and representational capacity. This framework identifies gestures and action demonstrations as a potentially crucial tool in instructional settings, when concrete actions may be necessary to scaffold new learners (e.g., Congdon et al., 2017) but the actions must appropriately

lead the child to insight about the broader concept being represented so as not to impair generalization to new contexts (Novack et al., 2014).

The challenge in distinguishing between goal-directed actions and demonstration actions is that the two might look the same. It is the intent of the actor that can distinguish the two. A teacher introducing a new concept, such as a mathematical principal, to a learner makes it clear that her actions are demonstrations. But what about when the learner repeats those actions? Is the learner's intent simple mimicry? Or might the learner, after some cognitive insight, be performing a true demonstrated action back at the teacher? To date, this crucial distinction remains somewhat elusive. We attempt to point out some clear cases of both goal-directed actions and action demonstrations throughout the rest of the chapter. However, it is worth noting that this particular distinction has been underutilized in the literature as a way to explain when action-based instruction is effective for learning and when it is not. We suggest that this area is ripe for future research and in need of more clear theoretical discussion.

In the remainder of the chapter, we (1) examine the time course of the development of gesture understanding in infancy and childhood; (2) explore the key features that differentiate hand gestures from object-directed actions and demonstration actions; and (3) discuss how those features lead to different internal representations. In meeting these goals, this chapter provides a framework through which to consider the role of the body in learning across the lifespan.

Gestures in Infancy and Early Childhood (0–4 years)

Productive language emerges well after infants can comprehend language. We see a similar pattern in gesture comprehension and production. For example, before they demonstrate deictic pointing gestures themselves, infants who are just 4–6 months of age will orient toward the object of a deictic point, suggesting that infants attend to this crucial communicative cue from an early age (Bertenthal et al., 2014; Rohlfing et al., 2012). Indeed, event-related potential (ERP) evidence with 8-month-old infants shows that babies display

differential neural activation to pointing gestures that correctly predict the location of an object, compared to pointing gestures that incorrectly predict an object's location (Gredebäck et al., 2010). These studies suggest that even pre-linguistic infants who don't yet produce pointing gestures are beginning to build a representation of deictic gestures that includes expectations about indicating a relevant piece of the external environment (i.e., "***this***" or "***that***").

By 10 months, still before most children have said their first word, children begin to produce deictic gestures. They will request specific objects in their environments with full-handed reaching gestures (Ramenzoni & Liszkowski, 2016) and, beginning between 10 and 12 months of age, with single-finger pointing gestures (Bates et al., 1979; Bates & Snyder, 1987; Liszkowski et al., 2012). Importantly, these early reaching and pointing gestures appear to be communicative—infants are particularly likely to produce them when there is a person watching who could bring them the object of their desire (Ramenzoni & Liszkowski, 2016). Infants who can successfully produce reaching gestures or spontaneous deictic gestures (e.g., Behne et al., 2012; Woodward & Guajardo, 2002) are also more likely to understand other people's reaching or pointing gestures. These findings suggest a continued link between production and comprehension—a full understanding of deictic gestures likely emerges in concert with infants' own motor experience producing these gestures in the context of wanting to indicate something specific in the external environment.

Perhaps the most compelling evidence that early deictic gestures directly support the formation of representations of semantic concepts comes from research showing that items infants frequently point to are more likely to show up in their spoken language repertoires than items they do not point to (Iverson & Goldin-Meadow, 2005). Although this is a correlational finding, there is also experimental evidence that pointing predicts word learning. In a 6-week-long training session, 17-month-old infants were assigned to one of three conditions: they heard a verbal label for an unknown object; they heard the label and saw a pointing gesture at the object; or they heard the label, saw a pointing gesture, and were encouraged to point at the object themselves. Infants who were encouraged to gesture not only gestured more during training sessions and interactions with their caregivers than children

in the other two groups, but crucially, they also developed larger spoken repertoires at follow-up several weeks later (LeBarton et al., 2015).

Infancy also marks the emergence of a phenomenon known as speech-gesture mismatching. A mismatch is when a speaker produces different information in gesture than in the accompanying speech (Goldin-Meadow, 2005). Far from being accidents or mistakes, these bimodal mismatches serve as a marker that the speaker is on the brink of conceptual change (Church & Goldin-Meadow, 1986; Novack et al., 2017; Perry et al., 1988). In infancy, when children first begin to produce spoken words while pointing, the information in the two modalities is largely redundant (although see Cartmill et al., 2014, for an alternative interpretation). For example, a one-year-old child may point to a cup [meaning, "***cup***"] while saying the word "cup". Several months later in development that same child may produce a speech-gesture mismatch, where the speech and gesture contain different but supplementary information. For example, pointing to a cup [meaning, "***cup***"] while saying "mama", roughly representing the idea of "mama's cup". Children who produce these mismatches go on to produce their first two-word verbal utterances three months later (i.e., saying, "mama cup"; Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005), suggesting that gestures can represent information that infants are not yet able to verbalize.

A bit later in development, between the ages of 2 and 3, children make great strides in understanding and producing iconic gestures. Iconic gestures require children to be able to map the form of a gesture to its meaning; interpretation of iconic gestures thus requires some symbolic understanding. It is not coincidental, then, that we see gains in the ability to understand and use symbols, such as using a smaller model of a room to represent a larger room (e.g., DeLoache et al., 1997), at the same time that we see an explosion in iconic gesture understanding and production (Goodrich & Hudson Kam, 2009; Novack et al., 2015; Tolar et al., 2008).

While language acquisition is, understandably, a primary focus for children in the first few years of life, it is not the only domain in which speech-gesture mismatches have been observed in very young children. In a study with pre-school-aged children, experimenters

asked children to name the number of objects on a card by first holding up the correct number of fingers and then saying the correct number out loud (Gibson et al., 2018). The purpose of giving the tasks in this order was to increase the likelihood that children would respond to the verbal task with ***both*** spoken responses and gestures. Indeed, many children did produce simultaneous gesture and verbal responses. Of those that were produced, many were mismatches, with different information in speech and gesture, and the majority of mismatches were ones in which the gesture represented the correct response. For example, on shown a picture of three items, a child might say "four" while holding up three fingers. Crucially, children who spontaneously produced these mismatches were significantly more likely to learn from subsequent high-quality instruction about the meaning of number words than those who did not. Like the very first speech-gesture mismatches we see in infancy, the authors argue that gesture is serving as a way for the child to represent correct information before they are able to fully verbalize that information, thus ultimately serving as a bridge between the external world (the number of objects on the card) and a true abstract representation of that concept (the number three).

Comparing Gestures to Actions (0–4 years)

At this point in the chapter, we pause our discussion of gesture development to think about how a child's ***own*** experience with specific goal-directed actions may support that child's understanding of representational action demonstrations and, eventually, representational gestures. In a landmark study, researchers showed that some 3-month-old infants were capable of inferring the goal of another person's reaching demonstration (Sommerville et al., 2005). In this study, all infants were habituated to a video wherein a hand reached toward and grasped (but did not move) one of two objects (e.g., a ball or a stuffed bear). In other words, the hand was ***demonstrating*** a goal-directed reach without actually completing the goal, which would be to "get the bear/ball" by bringing it toward oneself.

In the two possible test conditions following habituation, the objects switched places on the screen and the hand either continued to reach the same location but a new object (same location condition), or a new location but the same object (same object condition). The authors reasoned that if babies dishabituated more strongly to the hand reaching to the same location, this was because the infants expected the hand to reach toward, or "try to get" the object it had initially reached toward. In other words, if infants understood that the goal of reaching is to grasp an object, the hand reaching to the same location would be a violation of expectation.

So why did some babies show this pattern while others dishabituated to the two types of test trials at the same rate? To experimentally control the infants' own object-directed action experience to see whether that played a role in this phenomenon, half of the participants were given "sticky mittens", small mittens ﬁitted with Velcro, and a number of objects with Velcro attached to them. Typical 3-month-old infants are not capable of reaching and grasping an object, but the "sticky mittens" allowed the infants in that condition to experience a grasping-like contingent action. In other words, the babies could swat in the general direction of an object, and the object would stick to the mitten. The other half of the infants in the study served as same-age controls with no special action experience. After a brief training period, infants in the "sticky mitten" condition were signiﬁicantly more likely to view the actor's reach demonstration as goal-directed than infants in the control condition.

The ﬁindings suggest that an infant's own experience with ***goal-directed actions*** is tightly linked to that infant's ability to infer goal-directedness in other people's ***action demonstrations***. While gestures were not directly tested in this study, work summarized previously suggests that infants do not produce their own true reaching ***gestures*** until about 10 months (Ramenzoni & Liszkowski, 2016). Taken together, the ﬁindings suggest that children's own ***object-directed reaches*** precede and predict their ability to understand reaching ***demonstrations***, which, on a developmental scale, precedes the ability to perform purely ***representational*** reaching gestures. We can see the same general trajectory with other types of more complex actions. For example, one study showed that at 2 years of age when children are

quite adept at performing reaches and a wide variety of more complex object-directed actions, they still struggle to appropriately interpret another person's "failed action" demonstration, doing so only about 50% of the time (Novack et al., 2015). In this case, a "failed action" demonstration looks like an object-directed action in all ways except that the full action is not successfully completed. Thus, to understand and complete the goal of a failed action demonstration, children cannot simply imitate the experimenter exactly, they must make an inferential leap about the actor's intended goal. Crucially, the same study showed that despite the challenges 2-year-olds have in inferring the goals of failed action demonstrations, they are still signi cantly more likely to understand a failed action demonstration than a gesture demonstration. By the age of three years, both types of demonstration are equally successful. Again, this trajectory of understanding complex actions (doing the action precedes understanding an action demonstration, which precedes gesture understanding) parallels the trajectory reported in younger infants who are learning simple reaching actions and gestures.

Consistent with this idea that action interpretation precedes gesture interpretation, 2.5-year-old children will readily extract relevant information about an object from a handshape if a person is demonstrating a failed reaching action, but not if the person is using the same handshape in the form of a communicative gesture (Novack et al., 2018). Taken together, these ndings start to paint a picture of a general developmental story whereby a child's own experience with object-directed actions precedes their interpretation of action demonstrations, which, in turn, precedes their ability to understand representational gestures. This developmental trajectory lends credence to the general idea that, in early childhood, action demonstrations and gestures play a crucial role in linking external objects and the actions afforded by those objects with a rapidly developing and purely representational language and conceptual system. Understanding this link is crucial for understanding mechanisms of embodiment theory more broadly.

Interim Summary (0–4 years). Findings from early childhood suggest that in a period of extremely rapid language development and conceptual growth, children's own gestures play a central role in the

acquisition of novel concepts. Children use gestures to communicate and represent information that they cannot yet represent in speech. We see the emergence of speech-gesture mismatches, a fascinating phenomenon whereby children's gestures represent information that either supplements spoken language or, in the case of number, corrects it. We also see some preliminary evidence that action understanding precedes gesture understanding on both an ontogenetic time scale and within the acquisition of speciﬁc concepts. Next, we take a look at middle and late childhood, a developmental time period when language acquisition has begun to plateau but conceptual development continues to accelerate as children enter formal schooling. It is here that we can take another look at how gestures affect the development of new conceptual knowledge in more explicitly pedagogical contexts, and how producing gestures compares to producing actions in these instances.

Learning from Gestures in Middle and Late Childhood (5–11 years)

Mathematics has been the domain of focus for much research on gesture learning in children, in part because many concepts in mathematics lend themselves well to spatial metaphor and representation by spatial tools like gesture. Some researchers have even argued that all of the mathematics is grounded in physical metaphor (Lakoff and Núñez, 2000), which makes it a particularly appropriate target for research on tools like gesture, which can lead to the formation of new embodied representations. From a practical perspective, mathematical learning is of interest to researchers because it is a uniquely cumulative discipline where children who fall behind in math tend to stay behind (Duncan et al., 2007). Thus, it seems a worthy goal to ﬁgure out which tools help children acquire and retain new conceptual knowledge in this domain.

Research on gesture and learning with older school-aged children reveals some remarkable parallels with the ﬁndings from younger children summarized in the previous section of this chapter. For example, third and fourth-grade children who spontaneously produce speech-gesture mismatches when trying to explain their incorrect

answers to a mathematical equivalence problem (e.g., 4 + 3 + 7 = _ + 7) are more likely to learn from subsequent instruction than children who do not produce speech-gesture mismatches (Alibali & Goldin-Meadow, 1993). Again, this finding is believed to reflect the idea that a gesture can represent semantically correct information ***before*** a child is able to express that information in speech. For example, a child explaining her incorrect solution to a mathematical equivalence problem might ***say***, "I added 4 plus 3 plus 7 plus 7 and got 21" while ***gesturing*** either an equivalence gesture that simultaneously highlights the two sides of an equation, or a grouping gesture that indicates some understanding that the 4 and the 3 could be grouped and added to solve the problem (see illustrations of both examples in Fig. 23.2).

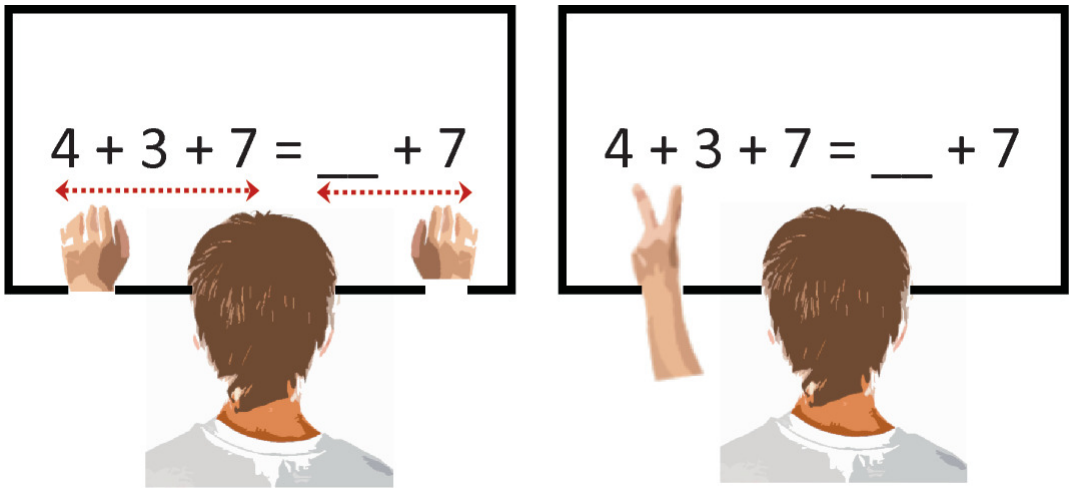


Fig. 23.2 Even if a child has an incorrect answer and verbal explanation, a child who displays evidence of correct problem-solving strategies or concepts in gesture is "ready to learn" and is likely to benefit from subsequent instruction. In the left panel, the gesture strategy represents the idea that the two sides of the equation should be equal. On the right, the gesture represents the idea that the first two addends can be grouped and added together to solve the problem

Although the ability to transcribe and identify a wide array of gesture strategies and algorithms can take months of training, one need not be an expert to pick up on these kinds of mismatching gestures in naturally produced speech. Research using the mathematical equivalence instruction paradigm has shown that naïve adults who watch videos of children explaining their incorrect answers will reference a child's ideas even if they were expressed only in gesture (Alibali et al., 1997). Moreover, without special gesture training, teachers will spontaneously adapt their instruction in

response to children's spoken ***and*** gestured strategies (Goldin-Meadow & Singer, 2003)—they give more extensive instruction to children who produce spontaneous speech-gesture mismatches. This finding suggests that, in real-world pedagogical contexts, spontaneously produced speech and gesture mismatches serve a key function for the instructor or teacher, even when that person is not highly trained in observing or coding gesture.

These findings suggest that speech-gesture mismatches serve an educational function for the learner in that they provide a signal to the teacher that the learner is ready for more advanced instruction. Children are, in a sense, shaping their own input. But speech-gesture mismatches might also serve a more direct educational function for the learner—speech-gesture mismatches might ***causally*** promote learning and insight, as opposed to simply serving as an indicator of cognitive readiness. To explore this possibility, researchers have experimentally manipulated the rates of gesture production in some participants. In one study, children solved mathematical equivalence problems and explained their answers to demonstrate a baseline spontaneous gesture rate (Broaders et al., 2007). Then one group was told to move their hands while explaining their answers to the math problems, one was told to keep their hands still, and a third was not given any special instructions as they explained the second set of six math problems. While all three groups produced a similar number of problem-solving strategies in speech, the children in the "told to gesture" condition produced more strategies in gesture, as well as more mismatches, and were subsequently more likely to learn from instruction than children in the other two experimental conditions. This finding suggests that gesture is causally linked to learning, and that gesture-speech mismatches do not serve as a mere reflection of children who are already poised to learn.

In follow-up research, experimenters asked children to produce ***specific*** gestures while repeating a mismatching spoken problem-solving strategy (Goldin-Meadow et al., 2009). In this case, children made a ***two-finger point*** to the first two addends on the left-hand side of an equal-addends math equation (see Fig. 23.2 for example), followed by a ***one-finger point*** to the blank space while saying an equalizer strategy out loud ("I want to make one side equal to the other

side"). Children learned signi cantly more in this condition than children who repeated the spoken strategy alone. In a third experimental condition, children were asked to make a ***v-point*** gesture to the incorrect grouping addends (3 and 7 in the problem represented in Fig. 23.2). The researchers found that, although producing this gesture was not as effective as gesturing to the correct grouping addends, children in this group still outperformed those who did not gesture at all. This study, and others like it, gives strong behavioral evidence that children are learning new conceptual knowledge from the form of the gesture itself, and not simply from the fact that the gesture focuses attention on relevant parts of the external environment.

There has also been work causally manipulating children's gesture production in non-mathematical domains, such as language learning. One such study looks at children's ability to learn the concept of palindromes, words that read the same forward and backward (e.g., "kayak"). In this study, 6- to 7-year-old children were given a brief lesson with either accompanying gestures or speech alone. Researchers also measured phonological competence as a way to gauge children's general ability to decode the speech sounds of novel words. The ndings revealed that children improved more from a lesson with gesture than without gesture, but ***only*** if they had higher phonological competency. This study suggests that gesture isn't necessarily bene cial for all children. Here, we have some evidence that gesture may only be accessible to children who have appropriate prior knowledge upon which they can map this abstract representational tool.

Comparing Gestures to Goal-Directed Actions (5–11 years)

To understand more about the bene its and drawbacks of gesture use in pedagogical settings, we can directly compare the learning outcomes of children who have been taught to produce a gesture to children who have been taught to produce a goal-directed action. In one study with rst-grade children, researchers gave children a lesson on a particularly dif cult type of linear measurement problem where the

object-to-be-measured was shifted away from the start of the ruler (see Fig. 23.3 for sample problems with the depiction of the training conditions). The researchers considered children's pre-test strategy as a general measure of competence and understanding prior to the beginning of the study. Some children, when shown a shifted-object problem, will consistently read-off the number at the end of the object, irrespective of where the object begins ("read-off" strategy). Other children will count the hatch-mark lines under the object, resulting in an answer that is always one greater than the correct answer ("hatch-mark counting" strategy). Children who use the read-off strategy are less conceptually advanced than children who use the hatch-mark counting strategy (Kwon et al., in prep). Children were trained to count units in the shifted-object problems by either making a thumb-and-forefinger gesture (gesture condition) or moving small plastic unit chips on top of the ruler (goal-directed action). Children with lower prior conceptual knowledge learned significantly ***less*** from the gesture than those with higher prior knowledge (Congdon et al., 2018). Interestingly, prior knowledge did not differentially predict learning from the goal-directed action; both groups learned quite well from that instruction in this context. These findings, which are similar to those from the research on learning palindromes, suggest that gesture, an abstract representational tool, might not be equally beneficial to all learners, particularly those with low prior conceptual knowledge of the topic being taught.

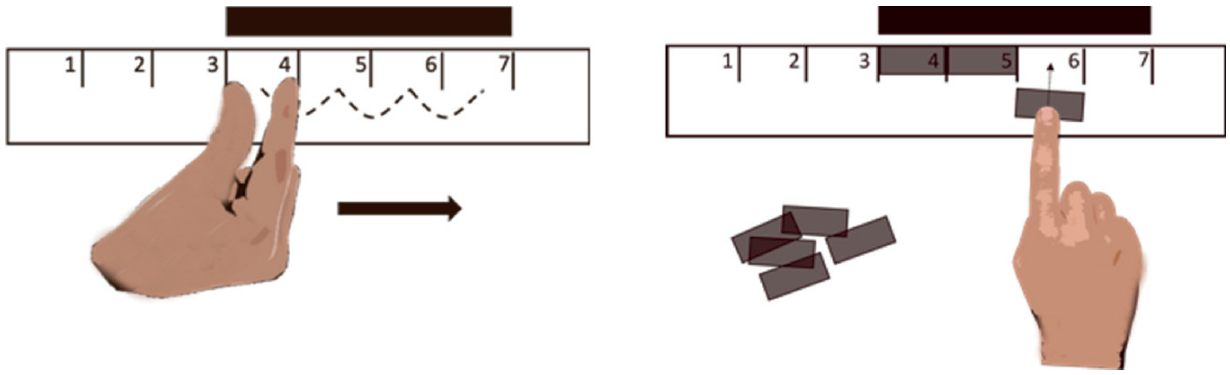


Fig. 23.3 Gesture-based movement (left) and action-based movement (right) on a shifted-object measurement problem. The correct answer is 4; a hatch-mark counting answer would be 5; and a read-off answer would be 7

While this property of gesture—that it is representational—may render it inaccessible to some learners, there is evidence that this property may be the seat of gesture's power when used in the right context. Some compelling evidence that gesture can provide a beneficially flexible representation when compared to other types of goal-directed actions comes from work with 5-year-old children in a word-learning task (Wakefield et al., 2018). In this study, children were randomly assigned to either a gesture lesson or an action lesson in which the stated goal was to learn a novel verb word (e.g., that "tifling" approximately means "squeezing"). The researchers found that all children in the study learned novel verbs on the objects on which they were trained, but the children in the gesture training condition more readily generalized that novel verb to a novel object. At this age, when children have improved their ability to understand iconic gestures, but are still struggling with some language skills (like generalizing novel verbs, Seston et al., 2009), gesture seems to allow them to form a representation of a verb that is not directly linked to a specific object.

Finally, there is work with older children using the mathematical equivalence paradigm that combines many of the themes we have discussed in this chapter so far. In this study, researchers directly compared gestures and goal-directed actions in a lesson with manipulated speech-gesture and speech-action mismatches to look at both learning and transfer in a pedagogical context (Novack et al., 2014). In one condition, children performed an abstract gesture (a ***v-point*** toward the two addends of a mathematical equivalence problem that could be added to solve the problem, followed by a ***single point*** to the blank). In a second condition, children performed a goal-directed action (picking up magnetic number tiles placed over the grouping addends and holding them over the blank). In the final condition, children were taught to pretend to pick up the tiles and hold them over the blank but did not actually touch them (concrete gesture condition). All children were taught to repeat a spoken "equalizer" strategy ("I want to make one side equal to the other side") while making their hand movements. The authors found that, although initial learning rates across all three conditions were comparable, only children in the two gesture conditions performed well on transfer problems—problems that were in a different format from those the children saw

during training. Children in the abstract gesture training condition were most likely to solve the most difficult transfer problems. These findings suggest that gesture has a flexible representational capacity that goal-directed actions do not.

Furthermore, a secondary analysis in this same study (Novack et al., 2014) looked for mechanistic clues as to ***how*** gesture was improving children's learning over and above goal-directed actions. The researchers looked at children's post-test explanations and found that many children referenced the verbal equalizer strategy that they had been taught to parrot back during training (e.g., "I made one side equal to the other side"). But children in the gesture condition were significantly more likely to use this explanation on problems they had solved correctly, whereas children in the goal-directed action training condition used this memorized explanation somewhat randomly. The authors argue that gesture functions, in part, by helping to clarify the content of ambiguous speech. The same benefit was not found for the goal-directed action.

As mentioned earlier, another common theme in the gesture literature is that not all children learn equally well from gesture-based instruction. Although this question was not investigated in the original publication, a re-analysis of the post-test data with a breakdown by prior knowledge corroborates this pattern (Fig. 23.4). If we look at pre-test strategy on mathematical equivalence problems in a way that is analogous to the measurement study described earlier (Congdon et al., 2018), we see that children with more rudimentary pretest strategies learned less from the abstract gesture condition than children with the more advanced, though still incorrect, pre-test strategies (pairwise comparison, $\boldsymbol{p} < 0.05$). Importantly, this pattern does not appear to hold for children in the other, more concrete conditions (action and concrete gesture).

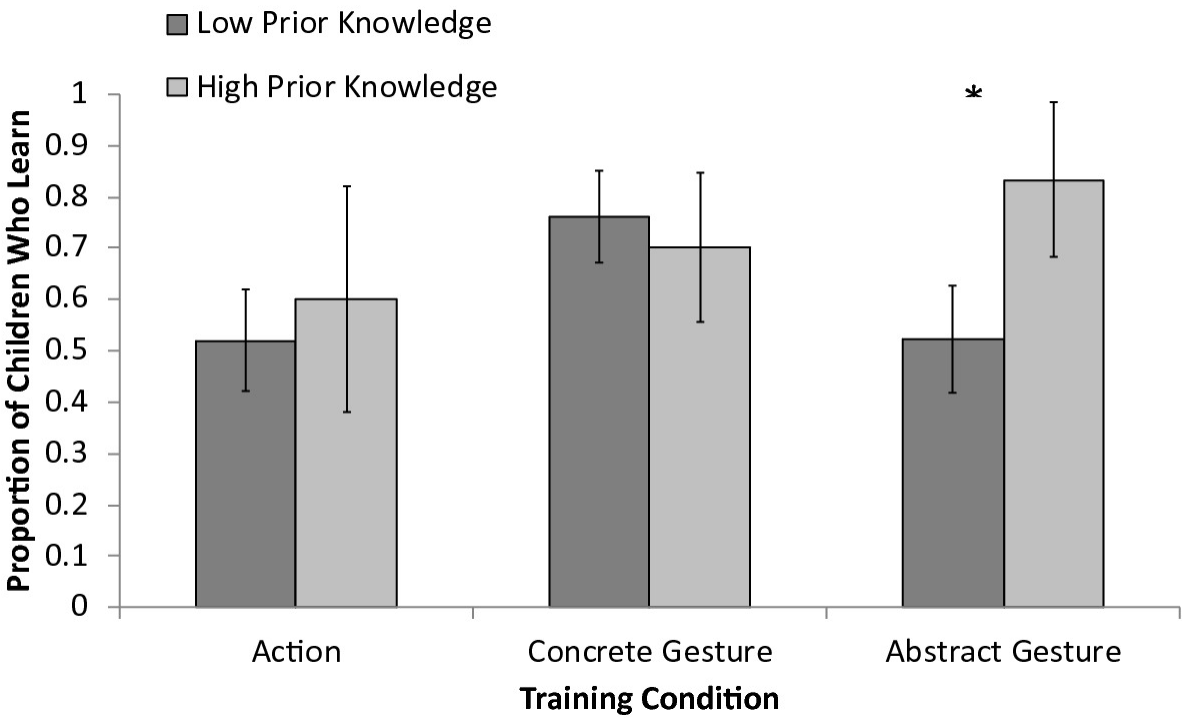


Fig. 23.4 A post-publication re-analysis of posttest data broken down by pre-test strategies (from Novack et al., 2014). In this case, low prior knowledge is characterized by simplistic pattern-based problem solving (like taking a random number from the left side and putting it in the blank). High prior knowledge is characterized by problem-solving strategies where children attempted addition of some of the addends, even if they were not the correct addends (such as adding up all of the numbers on the left hand side of the equation and putting that in the blank, or adding up all of the numbers in the problem and putting that in the blank). Bars represent ±1 SEM

Interim Conclusions (0–11 years). By looking across both early and middle childhood, and across multiple content domains, we see that gesture plays a remarkably similar role across development. In particular, we highlight that spontaneously produced speech-gesture mismatches seem to precede and predict learning, and that manipulating gesture to artificially increase or create speech-gesture mismatches improves learning outcomes as well. These results suggest that speech-gesture mismatches do not merely serve as an index of readiness to learn, but can be causally related to learning and the acquisition of new knowledge. Furthermore, we have evidence, across ages and domains, that goal-directed actions and gesture actions differ in key ways that affect learning outcomes. Gesture, a powerful but abstract representational tool, may not be readily accessible to all learners, depending on their stage in ***either*** ontogenetic development or conceptual development. That is, very young learners (infants) and

very naïve learners (those with low prior knowledge) both struggle to learn from gestures, particularly iconic or representational gestures.

In the final section of this chapter, we dig deeper into the mechanisms underlying gesture's impact in pedagogical contexts to try to understand exactly ***how*** gesture works as a learning tool.

Mechanisms of Gesture

One salient feature of gesture is that, like goal-directed actions, it engages the motor system. Any time learners can use multiple systems to represent information, they create a more robust and longer-lasting conceptual representation. Importantly, the connection between information that was learned through gesture and the motor system appears to outlast the active production of the gesture itself. That is, after producing gestures while learning new information such as musical melodies (Wakefield & James, 2011), new vocabulary words (Macedonia et al., 2011), or strategies for solving mathematical equivalence problems (Wakefield et al., 2019), participants show motor ***re***activation when confronted with the stimuli they had learned via gesture—even when they are not moving or gesturing. Furthermore, listeners seem to engage the motor system even when simply watching other people produce co-speech gesture (Wakefield et al., 2013), suggesting that learners need not be producing the gesture themselves to engage the motor system. In fact, asking listeners to move their own arms and hands, but not their legs and feet, interferes with their ability to process someone else's gesture (Ping et al., 2014).

In addition to engaging the motor system both during and after the initial learning, producing gestures seems to decrease working memory load. Although accounts on the precise relation between gesture and working memory differ slightly, there is good behavioral evidence that spontaneous gestures during difficult problem-solving or other working memory intensive tasks can help reduce the burden on working memory through cognitive offloading (see Cook et al., 2012, and Goldin-Meadow, 2005). Cognitive offloading can take many forms, such as writing down a shopping list on a piece of paper instead of trying to keep all of the items in working memory. Gesture appears to confer a similar cognitive benefit (Goldin-Meadow et al., 2001; Wagner

et al., 2004), particularly when the information expressed in gesture adds to information expressed in speech, rather than representing it in a redundant manner (Ping & Goldin-Meadow, 2010).

These studies, and others like it, suggest that gesture is likely doing more than just directing a learner's attention to key places in the external environment. Gesture seems to help form and maintain internal representations of new concepts in a powerfully embodied way. In support of this argument, one study looked at whether children's visual attention patterns during the learning process in a mathematical equivalence lesson predict learning scores at post-test (Wakefield et al., 2018). If gesture simply increases helpful looking patterns to lead to better learning outcomes, then the presence of gesture should not only heighten the rate of helpful looking patterns but also show a correlated boost in learning, when compared to spoken instruction on its own. Instead, the authors find that gesture fundamentally changes, or moderates, the relationship between gaze patterns during learning and post-test scores. In other words, gesture's efficacy cannot be fully explained by the way in which it directs a learner's attention. Instead, the gesture itself—likely through a combination of meaningful form and movement—is helping to create new conceptual knowledge that allows the learner to make sense of information in the external world in a novel way.

Is gesture unique in its ability to perform such a function? One argument to support this possibility is that gesture is almost always produced in the context of spoken language, and integrates with spoken language so that the two can work together seamlessly in pedagogical contexts. Although this may be true for genuine demonstration actions, it is ***not*** true for the vast majority of goal-directed actions (e.g., Church et al., 2014). In fact, we know that in conversational contexts, gesture and spoken language is effortlessly produced together by speakers, and effortlessly perceived together by listeners, and that perception is impaired if that synchrony is disrupted by even a few hundred milliseconds (Habets et al., 2011). In one recent study, the authors wanted to directly test whether the synchronous timing of speech and gesture was important to learning outcomes in children, or whether children were able to learn as much, or perhaps more, from a lesson that presented new information in speech and

information in gesture sequentially (Congdon et al., 2017). The authors find that children retain and generalize learning better when speech and gesture are presented simultaneously than when they are presented sequentially, and posit that the effect is driven by the fact that speech and gesture mutually disambiguate each other. This interpretation is consistent with the argument that speech and gesture share a common cognitive origin, which explains their effortless integration in communicative contexts (e.g., Loehr, 2007; McNeill, 1992).

Recent research has begun to explore the function of gesture in pedagogical contexts, and through various manipulations and comparison groups, has been able to demonstrate that gesture can direct visual attention, reactivate the motor system, reduce working memory load, flexibly represent new concepts, and integrate with and disambiguate spoken language. Although other pedagogical tools, such as goal-directed actions, drawings, or diagrams, may each have some of these features, none but gesture appears to have them all. This chapter has raised the idea that true demonstration actions—that is, representational actions that are produced with the specific intent to teach or demonstrate, may come closest to the ideals of gesture, but they still cannot match gesture in the flexibility of form. It is for these reasons that we argue that gesture plays a special role in embodied learning of concepts throughout the lifespan.

Conclusions and Future Directions

Taken together, the findings reviewed here suggest that gesture, a uniquely flexible representational type of bodily action, is a powerful tool for learning and communication. It gives young children a way to express and represent information pre-linguistically, and asking children to represent new ideas or information with their hands can help that new information make its way into the child's mind. Notably, the mechanisms that underlie gesture's power in learning and communicative scenarios show some remarkable consistencies across childhood. Across varied contexts, gesture can precede and predict language, and speech-gesture mismatches help to identify a learner who is on the brink of conceptual change. Asking a learner to

intentionally produce a speech-gesture mismatch can causally promote insight in a way that speech alone does not. These patterns are true whether we are talking about infants learning their first syntactic structures, three-year-olds learning the meaning of number words, or fifth graders learning pre-algebra concepts. Yet it is important to note that some of the features that make gesture powerful for learning—like the fact that it is not tied to particular objects and that it is flexible in its representational form—may make it inaccessible to learners just beginning to tackle a problem. To borrow a Vygotskian term, the information represented in gesture must be ***within the zone of proximal development*** for a child to understand and make use of the gesture in a learning scenario. Prior knowledge has been measured in a variety of ways that depend heavily on the target concept and age group—phonological competence, measurement pre-test strategy, spontaneous speech-gesture mismatches—but across all of these instances, children with lower competence in a particular domain learn significantly less from gesture in that domain than their more conceptually advanced peers.

Ongoing work investigating the mechanisms underlying gesture's role in learning suggests that it is a tool capable of integrating the body, language, and other systems in the brain in a unique way. Studying the impact of gesture on learning and communication across development makes a powerful case for the idea that the body is an integral part of the broader cognitive system. Moving forward, this developmental perspective on embodiment has raised several challenges. One pressing challenge is to formulate a theory of embodiment that flexibly accommodates the constantly shifting roles of both language and learning across development, and allows for predictions on both an ontogenetic time scale and on the much shorter time scale of conceptual change. While the current chapter notes remarkable similarities in the role that gesture plays across a variety of academic domains, age groups of participants, and types of gesture, there are so many factors at play that, for theoretical and practical educational purposes, it will be necessary to continue working on a framework that can predict exactly when and how the body can play a beneficial role in learning and conceptual development.

Acknowledgements

This work was supported by the National Institutes of Health Grant R01-HD047450 and by the National Science Foundation Grant BCS-0925595 to S. Goldin-Meadow; the National Science Foundation Grant SBE-0541957 (Spatial Intelligence and Learning Center, S. Goldin-Meadow is a co-principal investigator); and a grant from the Institute of Education Sciences, U.S. Department of Education (R305 B090025) to the University of Chicago in support of E. Congdon.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_24

24. An Evolutionary Perspective on Embodiment

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Abstract
From an evolutionary perspective, embodiment is fundamental. All aspects of brain function, including thoughts and feelings, must ultimately serve overt action or they would not have been supported by natural selection. The question then is how anything that is ***not*** embodied could have evolved. In this chapter, I will briefly review the evolutionary history of the lineage that leads toward humans, emphasizing the continuous elaboration of sensorimotor control mechanisms. These are fully embodied in the sense that none of their elements have any meaning outside of the context of the full control loop that includes the brain, the body, and the environment. However, in a few particular cases, specializations occurred that resulted in internal variables that became partially divorced from that sensorimotor context. Examples include the navigational map of the hippocampus, the categorization processes of the temporal cortex, and the symbolic utterances that control social interaction.

Keywords Embodied cognition – Evolution – Sensorimotor control – Neural representations

Differing Views on Embodiment

The term “embodiment” means different things to different people. Within cognitive psychology, it is used to suggest that features of the physical body play an important causal role in cognitive processing (Wilson & Foglia, 2017). For example, we can use parts of the body to off-load computational work (e.g., counting using our fingers), or to facilitate communication (e.g., by gesturing). In this sense, “embodied cognition” is a type of cognition—a computational system for manipulating representations—but one that goes beyond classical cognitive science by taking advantage of entities outside of the brain to provide constraints and grounding. It provides an increasingly popular alternative to classical theories (Fodor, 1983; Newell & Simon, 1972; Pylyshyn, 1984), which posited that all thinking is based on representations of knowledge with quasi-linguistic and symbolic properties. Embodied cognition takes a step away from some of those assumptions.

However, some would suggest that this step is not nearly big enough (Wilson & Golonka, 2013). Embodied cognition as usually practiced is really little more than another flavor of computationalism, which itself is just a variant of representational theories of mind (Chemero, 2009). All it does is add another tool to the toolbox of classical cognitive science without modifying the fundamental assumptions prevalent in the field. It still assumes that “cognition” is a computational process for manipulating representations, which still lies between “perception”, a system for computing representations of the external world, and “action”, a system for turning them into patterns of muscle contraction. And as such, it still suffers from the various problems that have long plagued the computational view, such as the “symbol grounding problem” (Harnad, 1990), the “binding problem” (von der Malsburg, 1996), and the general difficulty of mapping concepts from classical cognitive psychology to the neural circuits that actually exist in the brain (Brette, 2019; Cisek & Kalaska, 2010; Lebedev & Wise, 2002; Lindquist & Barrett, 2012).

Before discussing whether cognition is embodied or not, it is useful to consider from where the concept of cognition itself came in the first place. It is widely recognized that a “cognitive revolution” (Miller,

2003) occurred in the 1950s as a reaction to the behaviorism prevalent at the time, but the fundamental ideas about representation and computation date back at least to Thomas Hobbes (1588–1679), George Berkeley (1685–1753), and John Mill (1773–1836). Furthermore, the functional architecture whereby cognition sits between perception and action is much older still, and comes directly from a view that nearly everyone has rejected—dualism. The old philosophical notion that the mind is non-physical forced early philosophers such as Plato (425–347 BC) and Descartes (1596–1650) to conceive of two interfaces between it and the physical world: "perception" is what presents the world to the mind, and "action" is what plays out the mind's will upon the world. Behaviorists rejected the concept of the mind, and sought to find direct links between sensory input and motor output, but they ultimately failed to provide satisfactory explanations of the complexity of human or animal behavior (Chomsky, 1959; Tolman, 1948). And so, the non-physical mind was replaced by a physical computational process, "cognition", and the architecture remained. The received wisdom still assumes a "perception" system that builds internal representations of the external world (Marr, 1982), and an "action" system that executes representations of motor plans (Miller et al., 1960), with a "cognition" system between them that manipulates representations to store and retrieve memories, make decisions, and compute plans. Embodied cognition allows more interaction between these conceptual pieces, but it still suffers from the weaknesses of what Hurley (2001) criticized as the "cognitive sandwich model".

One reason why the architecture inherited from dualism has been retained in psychology is that terms such as "perception", "cognition", and "action" have become so deeply ingrained in our language that it is almost impossible to express questions about the brain or behavior without them. Entire traditions of academic specialization are defined around these terms, forcing new ideas such as "embodiment" to fit within their context. Consequently, embodied cognition is usually still seen as merely a type of cognition.

However, there has for a long time existed an alternative set of views, dating at least from the pragmatism of William James (1842–1910) and John Dewey (1859–1952), who argued against viewing the

brain as a machine for representing the outside world. Within that "eliminativist" tradition, there is space for a science of cognition that is quite different (Chemero, 2009). It is not focused on representations and computations but on dynamical systems whose role is not to build knowledge about the world but to control interaction with the world (Cisek, 1999, 2019; Van Gelder, 1995). Wilson and Golonka (2013) argue that once we recognize the undeniable fact that the body and environment play an important role in defining the dynamics of interaction, then many standard concepts of cognitive psychology lose their apparent necessity. For interactive behavior, embodiment is much more fundamental and much older than anything anyone would call "cognition". The body has always defined the activities in which the brain can engage, and from a biological perspective, all mental activities are only useful insofar as they have some external outcome. In fact, it has for a long time been suggested that bodily interactions with the world are the foundation within which cognition itself emerges (Clark, 1997; Hendriks-Jansen, 1996; Pezzulo & Cisek, 2016; Piaget, 1967; Thelen et al., 2001). In other words, embodiment is not an aspect of cognition—***it is the other way around*** (Cisek, 2008).

Here, I will describe a strategy for getting away from the constraints of conceptual distinctions such as "perception", "cognition", and "action" (Cisek, 2019). It involves stepping away from current debates and asking a different type of question: In a biological system, where do the real functional distinctions come from? The answer is of course: evolution. Distinctions between different systems emerge in evolution because they specialize toward distinct functional roles (e.g., eating vs. breathing). But these systems do not appear out of thin air. Animals did not suddenly invent lungs as they came out onto land—they gradually modified an existing system (e.g., the swim bladder) to extend its role in a way that made additional modifications possible. The same goes for neural systems, each of which is a specialization of an ancestral mechanism. This process of descent with modification, pruned by natural selection, is what produced the nervous systems we see today, all of which are products of a long history. Importantly, that history can be partially reconstructed, giving us a powerful strategy for deducing how different systems emerged over evolutionary time and yielding a conceptual taxonomy that

naturally maps to biological reality (Cisek, 2019). It is a different way to "carve nature at its joints", and I would argue that it is better than basing our conceptual taxonomy on outdated philosophical notions, such as dualism. Here, I will briefly summarize some of the key innovations along the lineage that leads to humans (see Fig. 24.1), based on a review of comparative studies of brain structures across a wide variety of species, coupled with my admittedly speculative account of the functional capacities that those structures conferred to our ancestors.

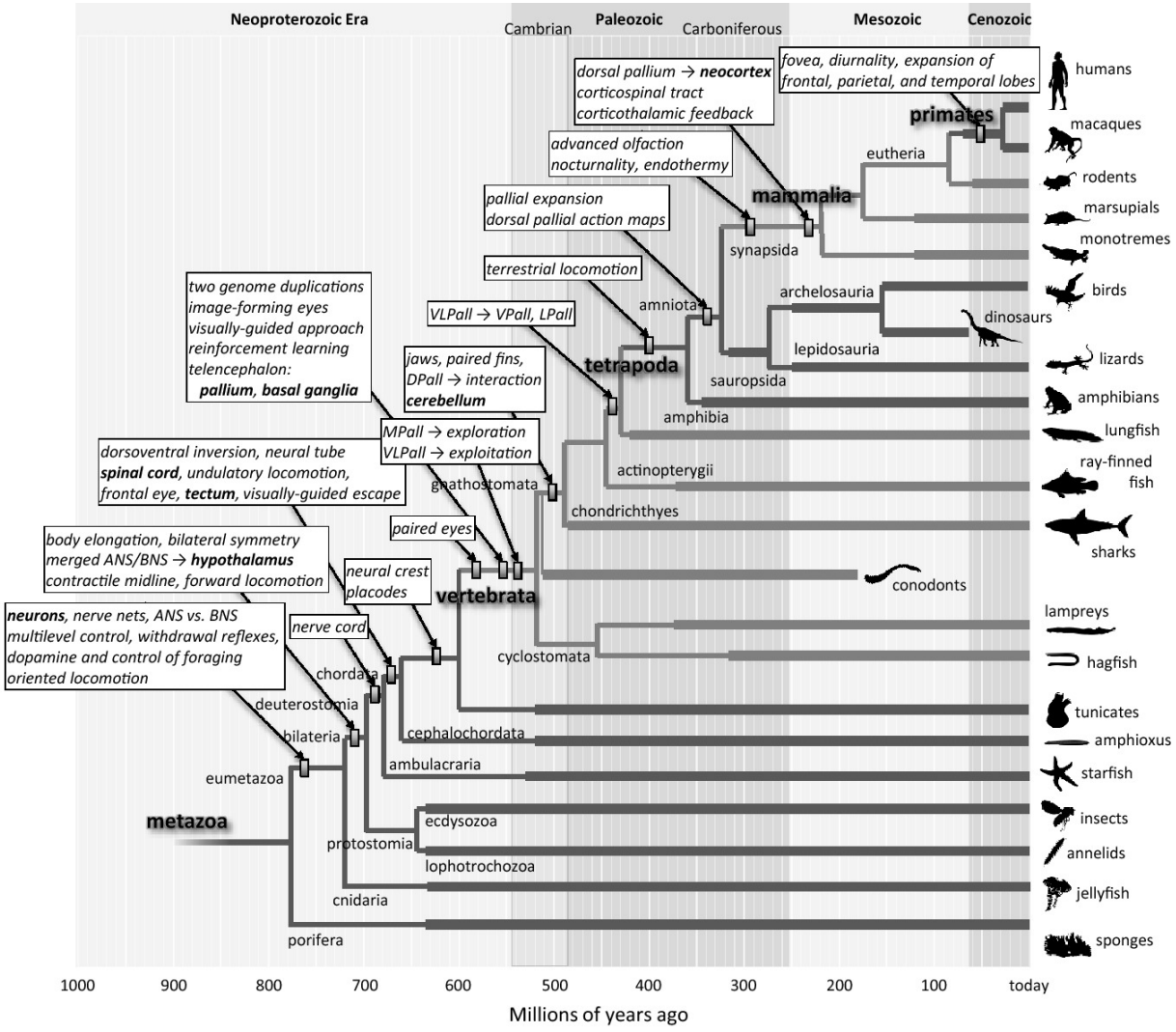


Fig. 24.1 The phylogenetic tree of animals expanded along the lineage that leads to humans. Branch points represent some of the divergences between different lineages, with timing estimated using molecular clock analyses. Thick lines indicate the presence of relevant fossil data from paleobiodb.org. Small rectangles indicate the latest estimated timing of innovations

described in the boxes. Many branch points and lineages are omitted for clarity. Silhouettes of example species are from phylopic.org.

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A Brief History of Brain Evolution

Life began approximately 3.6 billion years ago with chemical reactions that formed closed catalytic loops (Copley et al., 2007; Hordijk et al., 2010; Joyce, 2002; Kauffman, 1993; Vaidya et al., 2012). These simple chemical systems maintained a persistent structure by continuously resynthesizing their own elements (metabolism) and produced copies of themselves in the immediate vicinity (replication). These properties launched the evolutionary process, leading to additional innovations such as the emergence of DNA (Bedian, 1982; Crick et al., 1976) and cell membranes (Fox, 1965).

A cell membrane makes meaningful a distinction between two kinds of metabolic control. The first operates entirely within the cell, taking advantage of the reliable laws of physics and chemistry, and today we call it "physiology". However, control loops need not be entirely contained within the membrane. For example, some types of chemicals cannot be synthesized internally but must be absorbed from the external environment, in which they are distributed non-uniformly. Hence, if an organism finds itself in a nutrient-poor local environment, it may improve its situation simply by moving randomly and this is likely to bring it into a richer environment where more of the nutrient can be absorbed. Evolution can establish this type of control because it takes advantage of reliable laws of the statistics of nutrient distributions. Such control mechanisms, which extend into the environment, can be called "behavior" (Ashby, 1965; Cisek, 1999; Maturana & Varela, 1980; Powers, 1973).

From this perspective, the fundamental task of any behaving organism has nothing to do with processing information or building internal representations of the world. Instead, ***the task is to complement the dynamics of the environment such that the entire organism-environment system flows toward states that benefit the organism and away from those that don't.*** Although the membrane makes it meaningful to distinguish things within the organism and things outside of it, the fundamental functional unit is a control loop that

includes both. That loop can be characterized as a negative feedback controller, which acts to reduce any deviation from desirable states (Fig. 24.2). Let's call this deviation the "impetus" for action (Cisek, 2019). If the impetus is caused by internal needs (e.g., depleting nutrient concentrations), we refer to it as a "drive" (Hull, 1943). If it is caused by a change in the external world (e.g., a threat appears) we call it a "stimulus". In all cases, adaptive actions are those that eliminate the impetus (e.g., by finding and ingesting food or by escaping from the threat). They succeed by properly taking advantage of the "motosensory" contingencies that exist in the environment—thus complementing the dynamics and bringing the system to a desirable state. This is the essence of "embodiment", and the mechanisms that accomplish it exist even in single-celled animals. Thus, embodiment is not only more fundamental than cognition, it is even more fundamental than neurons.

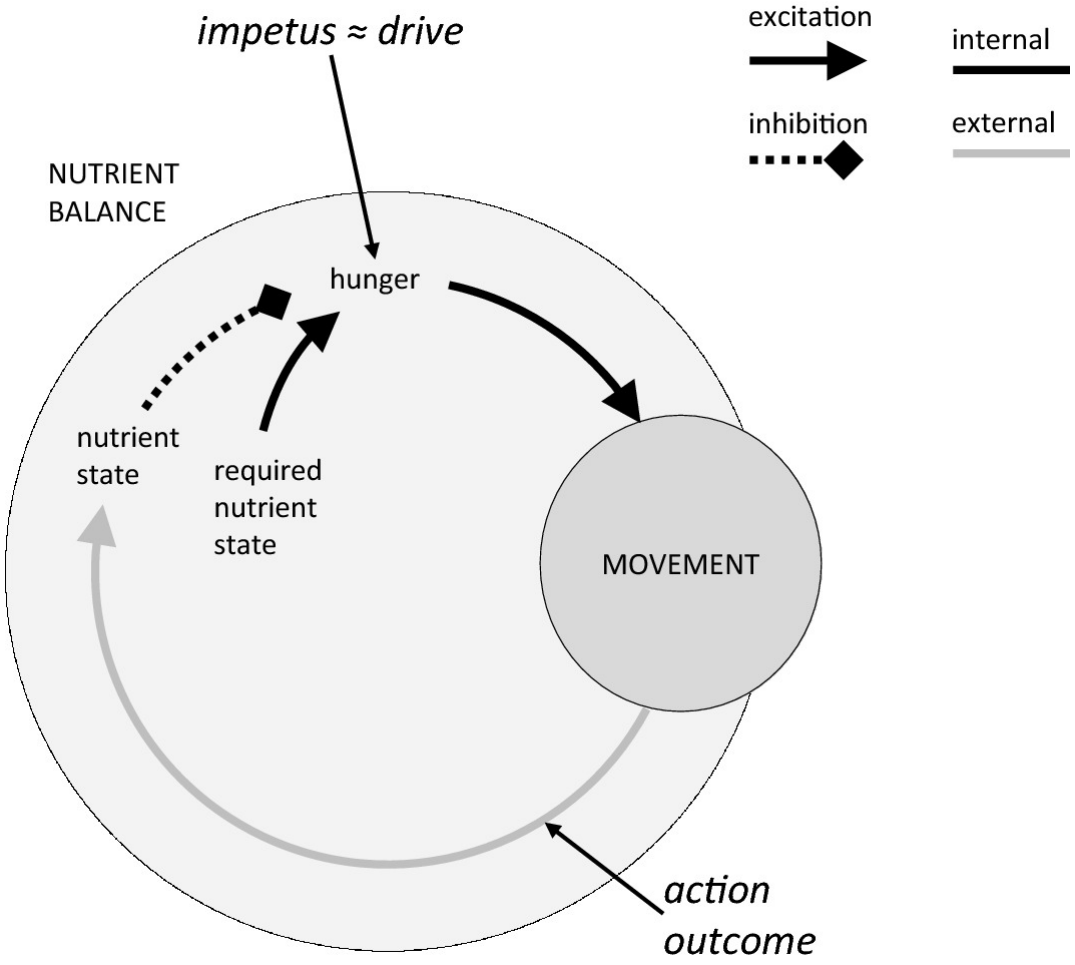


Fig. 24.2 Schematic of a simple control system. When the current nutrient state deviates from a desired state, locomotion is initiated, ultimately bringing the animal to a more desirable state. Reprinted with permission from Cisek (2019)

Because the dynamics that define the control of interaction through the environment are so different than the dynamics of control within the body, it is not surprising that physiological and behavioral control mechanisms have evolved in such different ways. It is also not surprising that neurons first appeared at the interface between the body and the world as a specialization of the external cell layer of multicellular animals (Brunet & Arendt, 2016; Jekely, 2011; Mackie, 1970). This occurred approximately 750–800 million years ago (Mya), after our lineage split from that leading to sponges (Ereskovsky & Dondua, 2006). Initially, these cells were "plurifunctional" and played both a sensory and a motor role. For example, some responded to mechanical deformation at their distal end with a mechanical contraction at their proximal end, thereby causing the body to withdraw from undesirable contact. Others contained chemical and photosensitive receptors and produced changes in the rest of the body through the secretion of hormones. Over time, different cells specialized to emphasize the sensory and motor roles, while others became specialized at coordinating signals in a network across the body, and today we call these "neurons".

At this point, we can usefully distinguish between cells that sense the environment ("receptors"), cells that act upon the environment ("effectors"), and cells that are intermediate ("interneurons"). While most theories of behavior and cognition begin with these distinctions and definitions, the functional organization of behavior did not. Even these distinctions emerged within an ancestral system. And even today, plurifunctional cells that blur the distinctions between sensory and motor functions can still be found in the brain of modern vertebrates (Fischer et al., 2013). What is most important, from a functional standpoint, is the overall operation of the control loop: its elements must work together and respect the motosensory contingencies that they exploit to reduce the impetus. This was recognized by John Dewey more than 120 years ago: "What we have is a circuit, not an arc or broken segment of a circle. This circuit is more truly termed organic than reflex, because the motor response determines the stimulus, just

as truly as sensory stimulus determines movement." (Dewey, 1896 p. 363).

The nervous system of an early eumetazoan consisted of a nerve net spread across its cup-shaped body. Around the opening of the cup (the "blastopore") was a ***blastoporal nervous system (BNS)***, consisting of an inner ring of contractile cells surrounded by an outer ring of mechanosensory cells (Arendt et al., 2016). These together implemented the oscillatory contractions that caused water to either flow inward or outward, implementing primitive types of "ingestion" and "propulsion". At the opposite, "apical" end of the body, there was a concentration of chemosensitive and photosensitive cells forming an ***apical nervous system (ANS)***. These measured local nutrient concentrations as well as ambient light and influenced the activity of the BNS through secretions of hormones. The two systems together could be seen as a hierarchy of control: The ANS governed the animal's behavioral state, such as circadian rhythms and the balance between resting, filter feeding, and locomotion toward richer nutrient concentrations—this would ultimately become what in modern animals is called the hypothalamus. The BNS, under the influence of the ANS, controlled the required type of sensorimotor activity, such as ingestion, propulsion, or rest—this would ultimately become the rest of the brain and spinal cord.

Thus, more than 750 Mya, we have a distinction between physiology (endoderm) and behavior (ectoderm) and within the latter, a distinction between high-level behavioral state control (hypothalamus) and lower level sensorimotor control (rest of the nervous system). Figure 24.3 shows a schematic of the control circuit in the context of nutrient balance. The high-level control was governed by the ANS, which secreted neuropeptide Y (NPY) to signal hunger (Billington & Levine, 1992; Meister, 2007; Minor et al., 2009; Schwartz et al., 2000; Voigt & Fink, 2015), which motivated one of two lower level behaviors controlled by levels of dopamine (DA) (Barron et al., 2010; Hills, 2006; Hills et al., 2015): If the current nutrient concentration was high, the animal engaged in local "exploitation" (staying within a small area while ingesting water), whereas if nutrient concentration dropped, it engaged in "exploration" (long-range movement to a new area).

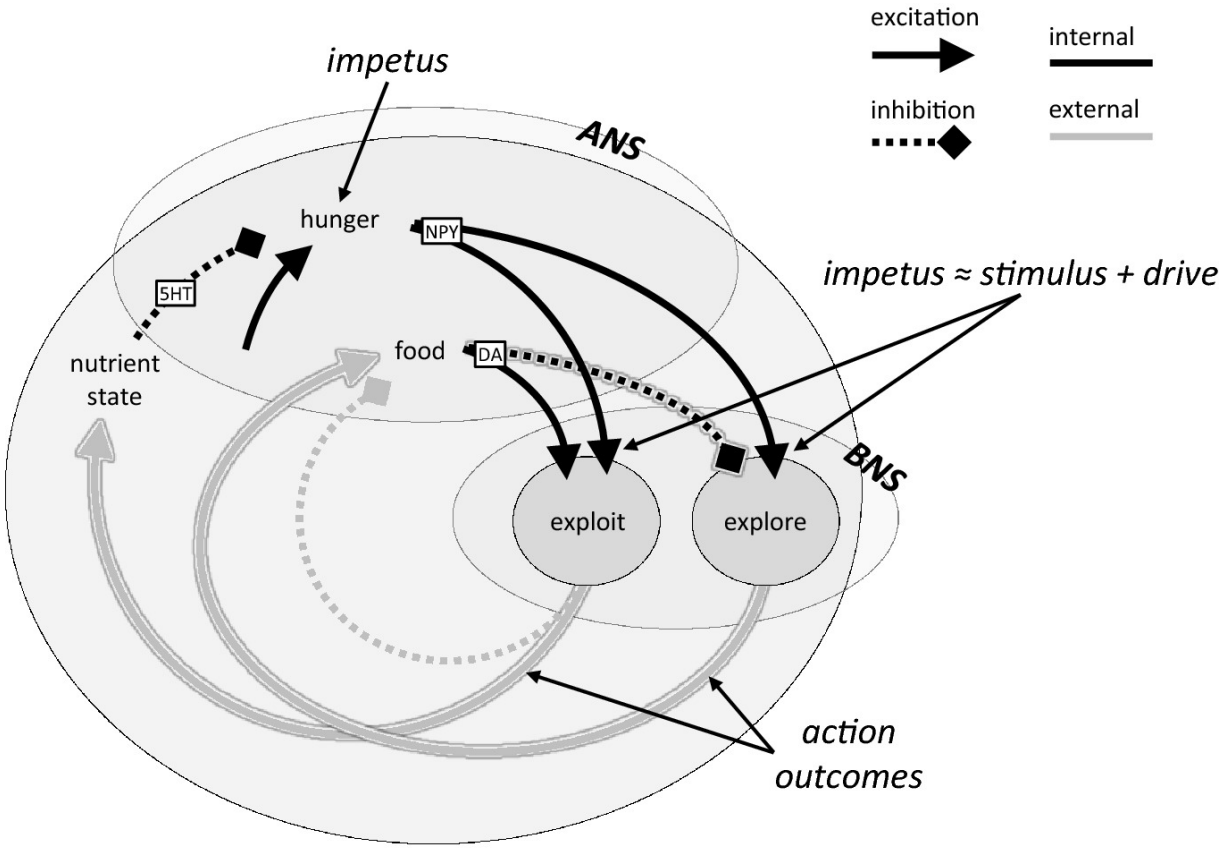


Fig. 24.3 Schematic nutrient control system elaborated into a high-level controller (ANS) and a lower-level controller (BNS) capable of two modes of locomotion: local exploitation and long-range exploration. 5HT: serotonin; ANS/BNS: apical/blastoporal nervous system; DA: dopamine; NPY: neuropeptide Y.

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The physical division between the ANS and BNS is still distinct in modern ***cnidarians*** (jelly fish, sea anemonies, etc.). In ***bilaterians*** (all vertebrates, insects, annelids, etc.), the ANS and BNS merged together into what Tosches and Arendt (2013) called a "chimeric brain". First, the radially symmetric eumetazoan body became elongated into an anterior–posterior axis, stretching the blastopore into a slit that later fused in the middle to form a digestive tube. Next, the ANS shifted downward to merge with the BNS on the anterior end of the body, which ultimately became the head. Here is where a centralized brain would eventually appear, but only in a few specific lineages, including arthropods, annelids, some mollusks, and chordates (Northcutt, 2012). The rest of the BNS remained on the ventral side of the body in protostomes (annelids, mollusks, arthropods, etc.), but in our branch,

the deuterostomes, the body inverted such that the entire nervous system now became dorsally oriented and separate from the mouth and digestive tract (Holland, 2015; Lowe et al., 2006). Finally, in chordates, the nervous system folded inward into the body, forming what defines the basic neural plan to the present day (Nieuwenhuys & Puelles, 2016).

To summarize, by the mid-Cryogenian period (about 650 Mya) our ancestors' nervous system could be subdivided into a high-level state controller (hypothalamus) that controlled the behavioral state through hormonal signals to a low-level controller (spinal cord) that implemented basic behaviors such as resting, eating, and locomotion. These animals fed on the thick microbial mat that covered the ocean floor, crawling to a new site when internal chemosensory signals indicated that the current one had been depleted. None of this required explicit internal representations of the external world, or distinctions between perception and action. Instead, behavior was implemented through a closed-loop system wherein each element—sensor, neurotransmitter, effector, as well as the relevant external condition—were dynamically coupled to establish a negative feedback control loop (Cisek, 2019).

About 540 million years ago, the world's fauna underwent a period of dramatic diversification known as the "Cambrian Explosion" (Erwin et al., 2011), driven in part by increased predation (Bengtson, 2002). At first, our chordate ancestors dealt with this turn of events using simple visually guided escape behavior. This was governed by a circuit consisting of projections from a single patch of photosensitive cells in the rostral part of the neural tube to a pair of dorsally placed structures in a region just caudal to the hypothalamus, which would later become the midbrain. Such a circuit can be seen in the cephalochordate ***Amphioxus*** and is probably homologous to the retino-tecto-spinal circuit that governs escape behavior in all vertebrates (Lacalli, 2006, 2018; Suzuki et al., 2015; Vopalensky et al., 2012). With the rise of predation during the Cambrian, however, it became increasingly efficient through what appears to be a series of important innovations.

First, as suggested by Butler (2000), the single frontal photosensitive patch split into two patches that migrated to the sides of the head (Shu et al., 2003). While these might have first both

projected to the tectal relays on both sides of the midbrain, in time the contralateral projections proved to be most useful. That is because with contralateral projections a dimming stimulus on the right side of the head stimulated the tectum on the left side, which in turn stimulated locomotion that first turned to the left, continuing until the stimulus was behind the animal and locomotion was oriented away. Next, the eye patches curved inward into cups, conferring spatial selectivity, and eventually formed the vertebrate retina (Lamb, 2013). Downstream projections retained the spatial selectivity, implementing escape behavior that was quickly oriented away from the threat before fast locomotion. This circuit of retinal projections to the contralateral tectum, which in turn predicts ipsilaterally to the brainstem and spinal cord, continued to implement fast escape behavior in all vertebrates.

In addition to the tectal circuit for escape behavior through ipsilateral downstream projections, part of the tectum specialized to implement ***approach*** behavior through contralateral projections. This can be clearly seen in the tectum of lamprey, a jawless fish whose ancestors diverged from ours more than 500 Mya. The lamprey rostral tectum receives contralateral projections from the posterior retina, which is sensitive to space in front of the animal and contains a wide variety of cells sensitive to features such as color (Jones et al., 2009), and projects contralaterally to the spinal cord (Kardamakis et al., 2015; Robertson et al., 2014; Stephenson-Jones, 2012). Simulation in this region produces orienting and approach behavior (Saitoh et al., 2007). In contrast, the rest of the tectum receives information from a wider visual field, projects ipsilaterally to the spinal cord, and when stimulated produces escape behaviors (Saitoh et al., 2007). The approach system of the rostral tectum implements a mechanism of lateral inhibition that produces “winner-take-all” behavior in approach actions, which is necessary in a world full of potential food sources (Cisek, 2019). Both of these systems have been found in a wide variety of vertebrate species, including fish (Bianco & Engert, 2015; Dunn et al., 2016; Herrero et al., 1998), amphibians (Ingle, 1983), birds (Hellmann et al., 2004; Mysore & Knudsen, 2011), and mammals (Comoli et al., 2012; Dean et al., 1986; DesJardin et al., 2013; Ellard & Goodale, 1988; Sahibzada et al., 1986).

Alongside the elaboration of tectal visuomotor circuits of approach and avoidance, another major advance in behavior during the early Cambrian epoch involved elaboration in foraging. The early hypothalamus consisted of two segments: a "terminal hypothalamus" at the rostral tip of the neural tube, which governed internal physiological control through hormone secretions; and a "peduncular hypothalamus", which governed state control through synaptic signals to the rest of the nervous system. It was this second segment that expanded into what would become the telencephalon (Puelles et al., 2013). It consisted of two regions. The outermost part was the "pallium", which controlled local exploitation and long-range exploration governed by tonic levels of dopamine, as discussed above. Just ventral was the "subpallium" (basal ganglia), which arbitrated between these behavioral strategies (Grillner et al., 2005; Redgrave et al., 1999; Robertson et al., 2014; Wickens & Arbuthnott, 2010), and in uenced approach versus avoidance behavior through projections to the midbrain. Importantly, this arbitration was modulated by reinforcement learning driven by reward signals provided by phasic "bursts" of dopamine (Ginsburg & Jablonka, 2010).

Although the telencephalon originally governed both exploitation and exploration through a single circuit, the different demands of these behaviors led to specialization. Local exploitation is driven by short-range odors and visual "key stimulus" cues and reinforced by immediate reward signals obtained by ingesting food. In contrast, long-range exploration is driven by odor gradients and distant "con guration" cues (Jacobs, 2012; Jacobs & Schenk, 2003), and is reinforced by a delayed increase in background reward rate. Presumably, it was for this reason why the telencephalon specialized into two systems fairly early on. Local exploitation was controlled by the lateral pallium—which would become the olfactory bulb, piriform cortex, insula, and neocortex—and lateral parts of the subpallium, which would become the nucleus accumbens, ventral striatum, caudoputamen, globus pallidus, and the subpallial amygdala. Long-range exploration was controlled by the medial pallium—which would become the hippocampal complex—and medial parts of the subpallium, which would become the septal nuclei (Puelles et al., 2013).

The early vertebrate nervous system described above, which was present half a billion years ago, contained almost all of the basic pieces of mammalian brains as well as their gross topological organization (Ocana et al., 2015; Robertson et al., 2014). The final major innovation occurred shortly after our lineage diverged from lamprey, with the early jawed vertebrates. It involved an elaboration of the dorsal hindbrain into the cerebellum, an adaptive filter that allowed our ancestors to predict the sensory consequences of their own motor activity (Bell et al., 2008; Bodznick et al., 1999; Montgomery & Perks, 2019; Montgomery et al., 2012). This allowed them to cancel out self-generated sensory signals and thus be more sensitive to external inputs (such as prey), and to overcome the transmission delays and complex second-order dynamics associated with getting bigger and faster. In short, it allowed them to become highly effective predators, leading to a dominant role in the ancient oceans.

About 400 Mya, our ancestors began to emerge onto land, modifying their swim bladder into lungs (Benton, 2015), their fins into legs (Pierce et al., 2013), and their spinal cord organization to make possible new modes of legged locomotion (Ijspeert et al., 2007). Life on land opened up many new opportunities and demands and encouraged a vast expansion of the behavioral repertoire. It offered a much greater visual range, encouraging further expansion of retinotectal circuits for visual guidance of approach and avoidance. It faced animals with new demands, such as avoiding thirst and controlling body temperature across much larger fluctuations of external conditions. Because our amphibian ancestors were so dependent on proximity to water, they could not venture far inland until they became capable of more sophisticated navigation strategies by elaborating the medial pallium and taking greater advantage of the clarity and range of vision in air.

During the early Carboniferous epoch, some of our ancestors completely abandoned an aquatic lifestyle by developing a “private pond” for their offspring—an amniotic sac enclosed in a protective shell we call an egg. Soon after, about 350 Mya, these animals diverged into two branches that survive to this day: the sauropsids, which include reptiles and birds; and the synapsids, which evolved into mammals. Sauropsids dominated the diurnal niche, further expanding the tectum and the tecto-recipient regions of the lateral pallium. These

regions expanded into what is known as the “dorsal ventricular ridge”. According to Puelles and colleagues (2017), this is homologous to what in mammals forms the piriform cortex, insula, and claustrum, though a debate exists between alternative proposals (Striedter, 2005). Sauropsids were highly successful (despite the famous demise of the dinosaurs), and one branch, the birds, attained impressive levels of complex behavior. However, since our interest here is on the human lineage, birds provide only limited insights. That is because at the time our synapsid lineage diverged from sauropsids, our common ancestor was nothing like a bird or a human. Thus, aside from the potential interest of convergent evolution, the innovations of birds do not tell us much about the innovations that shaped our own brain.

In contrast to the diurnal sauropsids, some synapsids became nocturnal, and these are the ones that survived to become mammals. Our nocturnal ancestors lost trichromatic vision and instead elaborated their auditory and olfactory systems, developing the ability to control body temperature (Lovegrove, 2017). In contrast with sauropsids, they elaborated a different part of their telencephalon, the “dorsal pallium”, which happened to exhibit a curious developmental process: its cells migrated into layers according to an inside-first/outside-last pattern. The consequence of this is that unlike sauropsids, whose thalamopallial projections wind up to be tangential, in mammals the thalamopallial projections form columns radiating out from the ventricular surface. This arrangement has the great advantage of being highly expandable: the mammalian dorsal pallium can grow like a balloon without incurring the connectivity costs that would stifle the growth of a structure in which projections must travel tangentially across the expanding territory. Thus, the dorsal pallium of mammals could grow dramatically into what we now call the neocortex, with each portion maintaining its ancestral connections with sensory input, descending output, and recurrent loops with the basal ganglia and cerebellum. The existing architecture of parallel sensorimotor streams, each specialized for one aspect of the animal’s behavioral repertoire, could be expanded and parcellated to support a wider range of behaviors. For example, in the context of foraging, local exploitation could expand from simple types of approach and ingestion behaviors

to a great variety of sniffling, burrowing, reaching, and grasping behaviors.

In mammals, the repertoire of behaviors typical for a particular species is implemented through a set of parallel sensorimotor "action maps" in the dorsomedial part of the mammalian neocortex (Graziano, 2016; Graziano & Aflalo, 2007; Kaas & Stepniewska, 2016; Kaas et al., 2011; Stepniewska et al., 2009). Each of these integrates visual and somatosensory information about the potential actions that are possible within the immediate environment—the opportunities for action that Gibson (1979) called "affordances". Each is dedicated to a given type of action and processes spatial information in a particular reference frame adapted to that type of action—retinotopic for gaze control (Snyder et al., 1998), hand-centered for reaching (Buneo et al., 2002), object-configuration based for grasping (Baumann et al., 2009), etc. Each is interconnected with frontal motor regions controlling the appropriate set of effectors—head and eyes, body and arm, arm and fingers, etc. While this region was relatively small and simple in the earliest mammals (Kaas, 2017), it grew dramatically as behavioral repertoires expanded, ultimately becoming the visual, retrosplenial, parietal, sensorimotor, and cingulate cortex. Activity in this dorsomedial neocortical sheet specifies, in parallel, the great variety of species-typical actions that are possible at a given time (Cisek, 2007).

Of course, all of those potential actions cannot be performed at the same time. A competition must take place to select the most appropriate action for the present situation. This can be subdivided into at least two different types of selection processes: (1) selection ***between*** behavior types; and (2) selection ***within*** a behavior type. Cisek and Thura (2018) suggest that the first type of selection involves projections from the basal ganglia, which selectively invigorate a given cortical action map, while the second type of selection occurs within each action map. For example, consider a primate foraging berries from among a group of bushes. If no bush is within reach, then the first task is to select one for approach. This involves selectively invigorating the gaze/body orientation system in the lateral intraparietal cortex and frontal eye fields (Colby et al., 1996; Schall & Thompson, 1999), followed by a competition within that system biased by information about the estimated richness of different bushes. Once oriented toward

a bush, the animal can engage locomotion to approach it. Now it faces a new task, selecting a berry to eat. This again involves invigorating the gaze system as well as the visually guided reaching system of the medial intraparietal and dorsal premotor cortex (Boussaoud & Wise, 1993; Johnson et al., 1996; Kalaska & Crammond, 1995). The decision on which berry to grasp is made within the cortical action map, continuing with repeated grasp and bring-to-mouth movements involving anterior intraparietal and ventral premotor cortex (Baumann et al., 2009; Graziano & Gross, 1998). This process continues, but as the berries are being depleted, a decision gradually emerges to switch from the current bush, suppressing the reach, grasp, and bring-to-mouth behaviors, and instead again invigorating body orientation and locomotion systems.

The above example includes a variety of decisions and actions, and all of them require information to bias selection both between different behaviors and within each action map. Most relevant for this selection are signals on the relative value of different specific actions (e.g., reaches toward berries of different sizes), as well as signals relating the current rate of reward relative to the estimated richness of the immediate environment (e.g., how many other berries could be found in other bushes). The first of these types of signals appears to involve a ventrolateral part of the neocortex, just adjacent to the spatially topographic dorsomedial neocortex, which is non-topographic (Finlay & Uchiyama, 2015). It extends from a visual area at the caudal end of the telencephalon to orbitofrontal regions at the rostral end. In primates, expansion caused this region to curve around the insula, such that the caudal portion now forms what is the temporal lobe and the "ventral visual stream" (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). This region receives input from the primary visual cortex, but instead of retaining spatial topography, it emphasizes the foveal region and instead processes information so as to "untangle" visual features to detect task-relevant key stimuli and classify categories of object identity (DiCarlo & Cox, 2007). This information projects along the ventrolateral neocortex and is combined with interoceptive signals from the insula to produce estimates of the value of foveated objects at the rostral orbitofrontal regions (Yoo & Hayden, 2018), learned through reinforcement based

on reward prediction signals (Schultz et al., 2000). These are then used to bias the information in the action maps in the dorsomedial cortex, resolving the competition between currently available affordances (Cisek, 2007), such as the many potential reaching movements toward different berries in a bush.

Reward prediction signals can also be used to select ***between*** different types of actions, such as continuing to reach berries versus walking over to another bush. This decision appears to involve a competition between the orbitofrontal cortex and the anterior cingulate cortex, where neurons have been shown to build up activity as a current foraging "patch" is depleted and signaling the decision to switch to a new patch (Hayden et al., 2011). Human imaging studies have likewise suggested that orbitofrontal regions "vote" for staying and engaging with a currently presented reward while anterior cingulate regions instead motivate the decision to switch and to search for something better (Kolling et al., 2012). Thus, the foraging decision could emerge as a competition between these two systems (Rushworth et al., 2012), influenced by motivating signals from the basal ganglia.

To summarize, the evolution of the primate brain involved a continuous expansion of control systems, with a progressive differentiation of circuits specialized for different aspects of behavior, which are still evident in modern brains. Internal metabolic control is implemented via endocrine secretions from the first "terminal" segment of the hypothalamus, while external behavioral control is implemented by the second "peduncular" segment, via its synaptic projections to the rest of the nervous system, controlling closed-loop interaction with the environment. Because behavioral control is an infinitely expanding challenge, the circuits that govern it have experienced a fantastic degree of expansion and differentiation over hundreds of millions of years. In vertebrates, these include two sensorimotor systems: tecto-spinal circuits for fast approach and avoidance, and telencephalic systems originally dedicated to foraging. This latter system includes a medial pallial system for exploration and a lateral pallial system for local interactions, as well as a subpallial system for selecting between different behavior types. In mammals, a neocortical system emerged within the dorsal subdivision of the lateral

pallium, implementing a set of action maps for controlling species-typical actions guided by the affordances of the external environment, as well as mechanisms for identifying key stimuli to produce value signals for biasing selection. This sensorimotor, embodied context was the ancestral state within which the primate brain evolved, leading to more sophisticated behavioral strategies that we are tempted to label as cognition (Passingham & Wise, 2012; Pezzulo & Cisek, 2016).

Returning to the Questions of Representations and Embodiment

The story of brain evolution outlined above is admittedly speculative. It is based on strong comparative and developmental data on the fundamental organization of the vertebrate nervous system, as well as detailed physiological analyses of specific neural circuits that govern behavior, but it also includes a number of proposals that have not, to my knowledge, been tested experimentally to date. The functional story outlined above must therefore be taken with some caution, and it is likely that some of its more speculative steps will prove to be incorrect. Nevertheless, although some of the details may be incorrect, the basic underlying premise is difficult to deny: the brain is a product of evolution. Given that premise, some important conclusions can be drawn regarding the questions of representations and embodiment.

First, it is clear that embodiment is fundamental, and much older than any type of "cognition" worthy of the term. Even the earliest organisms had to control their state, whether through physiological processes within the body or behavioral interaction through the environment. Indeed, the whole point of behavior is to keep oneself in a desirable state, and all the actions we take are ultimately serving that basic role. As soon as the control loop elongates to include things like neurons, their activity will perforce be related to their task of control. It will correlate in non-trivial ways with properties and states of the external environment, not to build knowledge but simply because of dynamical coupling. In this sense, we can conceive of a notion of "pragmatic representations"—neural activity patterns that govern the operation of a control mechanism, and therefore perforce correlate with multiple aspects of the environment as well as subjective

properties of the organism. For example, when monkeys are faced with potentially reachable targets, neural activity in the dorsal premotor cortex reflects the direction and distance of reaching movements to those targets (Cisek & Kalaska, 2005; Fu et al., 1993; Messier & Kalaska, 2000; Wise, 1985), but is modulated by attention (Lebedev & Wise, 2001), the intention to reach or not (Kalaska & Crammond, 1995), the relative value associated with different targets (Pastor-Bernier & Cisek, 2011; Roesch & Olson, 2003), the evidence in favor of one movement versus another (Thura & Cisek, 2014; Wang et al., 2019), and even reflects the subjective setting of the trade-off between choosing quickly versus carefully (Thura & Cisek, 2016). This is not because the dorsal premotor cortex "encodes" these variables in some way that will later be "decoded" downstream, but simply because it is part of a dynamical system whose role is to ensure that reaching actions unfold toward the most desirable goals (Churchland et al., 2010).

Some might question whether "pragmatic representations" even qualify as representations at all, because they mix variables in ways that make decoding them impossible (Brette, 2019). Indeed, the decoding ability is irrelevant as long as the dynamics yield the right outcomes. Nevertheless, describing these kinds of activity patterns as "representations" is useful because it allows one to conceive of them as lying at one end of a conceptual spectrum at the other end of which lie what we could call "descriptive representations". Descriptive representations are those usually discussed in cognitive science—they are patterns of activity whose explicit role is to convey information about the world or the organism, preserving some kind of decodable relation between the representation itself and whatever it encodes (the "referent").

Conceiving of pragmatic and descriptive representations as the ends of a spectrum is useful for several reasons. First, it recognizes that different people are already using the word "representation" in these very different ways. Second, it makes it possible to discuss intermediate types of representations instead of arguing about the extremes. But most importantly, it makes it possible to discuss how they might have differentiated over evolutionary time. In other words, seeing representations on a spectrum makes it possible to discuss how

abstract “descriptive” representations could have emerged within an embodied control system from representations that were initially purely “pragmatic”. Below, I brie y describe three examples.

Possibly the earliest example of a largely descriptive representation evolving from a pragmatic one arises in the context of navigation behavior. In early eumetazoans, dopamine signals governed the shift from local exploitation to long-range exploration behavior, which led to specialized systems in early vertebrates. The medial pallium was specialized for dealing with the condition (impetus) of “hunger + no food” by guiding locomotion away from nutrient-poor regions and toward nutrient-rich ones. As it elaborated, it made increasing use of a conjunction of cues (olfactory gradients, visual landmarks) that were reinforced by previous experiences—e.g., experiences in which they were used for navigation that led to a richer environment, eliminating the “hunger + no food” impetus, and to the eventual satisfaction of hunger. In those ancestral animals, the associations between gradients, landmarks, self-motion and desirable outcomes were only made in the course of seeking food, while the animal was hungry and when ingestion ultimately led to reinforcement. In other words, the map only got built while a hungry sh was swimming around in search of food.

However, suppose that some of the learning mechanisms that were used to build that map continued to function even in the absence of the motivating impetus. The lawful relationships between one’s own motion and external gradients and landmarks are still there regardless of what motivates the motion. The sh could swim around even when not hungry and as it did so, it could still build a map. It could still link places in that map with cues related to food, even if it had no interest in the food. Most importantly, when the sh ***did*** become hungry later, it could use that map to nd those places again. Once you have a learning mechanism for building a map, and the behavioral capacity to use that map, it becomes possible and very useful to gradually divorce the learning mechanism from its original motivating impetus, producing something that could be called objective knowledge.

In other words, an ancestral system for constructing a map of “where I found food when I was hungry” could have become a system for constructing a map of “where there is food”. This would have been a

game-changing innovation. Now, even aimless swimming would contribute to survival by helping to construct and update a map-like knowledge of the world that could later be used to control the nutrient state. Furthermore, that map could be linked not just to food, but to safe havens (places in which fear was reduced), the presence of mates (where the reproductive drive was satisfied), or any cues that bear upon the reduction of some relevant impetus. That map would still be filled with meaning, insofar as the cues used to build it are behaviorally relevant in the context of motivated navigation, but it would qualify as a "descriptive representation" because it would indeed capture abstract knowledge about the world that may or may not be immediately used for action.

Another example, also already mentioned, concerns the evolution of visual mechanisms for object recognition and classification. From a pragmatic perspective, what interactive behavior needs most are signals relevant to the current behavioral state. That is, sensory "key stimulus" features associated with berries (e.g., small red object on a green background) are most useful for guiding foraging actions when one is hungry. And indeed, cells responsive to food-related visual cues are found in the insula, but they do not respond unless the animal is hungry or a sense of hunger is artificially induced through stimulation of specific neurons in the hypothalamus (Livneh et al., 2017). One should expect such context-dependent, "pragmatic" representations to be common in the nervous system and directly involved in the control of feeding behaviors. Similarly, cells responding to sensory cues indicating shelter (dark aperture just large enough for the animal, but too small for its predators) should be most strongly activated in the presence of predators. Conversely, food detectors should be suppressed in the presence of predators, ensuring that even when very hungry, one forgoes food so as not to become food oneself. However, as noted above, as an animal becomes more complex and, for example, becomes capable of building and using navigational maps of its surroundings, so it becomes beneficial to increasingly divorce key stimulus detection from its motivational context and produce activity patterns that are strongly related to specific properties of the world and largely independent of internal states. This can, over time, lead to a specialization of sensorimotor systems to include both pragmatic and

descriptive representations related to the same objects, yielding the kinds of putatively "pure" visual object recognition mechanisms found in the inferotemporal cortex of primates (DiCarlo & Cox, 2007; Logothetis & Sheinberg, 1996).

Developing representations that categorize objects into particular classes is useful because there really do exist distinct classes of objects in the world, and each of them tends to make possible a specific constellation of affordances. Fruits and other animals are obvious examples, but so are geometric classes like horizontal surfaces that provide support, vertical surfaces that act as obstacles, and surfaces slanted at a particular angle that happens to be climbable to the perceiving agent. Note that categorical representations need not be fully "descriptive", because they can be preferentially linked with specific action systems (fruits for reach selection, trees for refuge selection, etc.). Nevertheless, as in the example of the medial pallial cognitive map, the mechanisms that recognize categories of objects could have gradually become divorced from the mechanisms that use those objects for direct sensorimotor interaction.

Probably the most dramatic examples of descriptive representations arise in the context of language. From a traditional perspective, linguistic communication is seen as the transmission of information from one agent to another, for the purpose of conveying knowledge. As such, it seems fundamentally "descriptive" and it is difficult to imagine how it could have evolved from sensorimotor mechanisms. It is also difficult to imagine how meaning is encoded in the message (Harnad, 1990).

However, there is another way to view communication, in general, and it is also in the context of control (Cisek, 1999): While physiology is control within the body, and behavior is control through the environment, communication is control ***through other creatures*** (Fig. 24.4). And like physiology and behavior, it works by exploiting reliable motor sensory contingencies, in particular those that are implicit in the behavior of those other creatures.

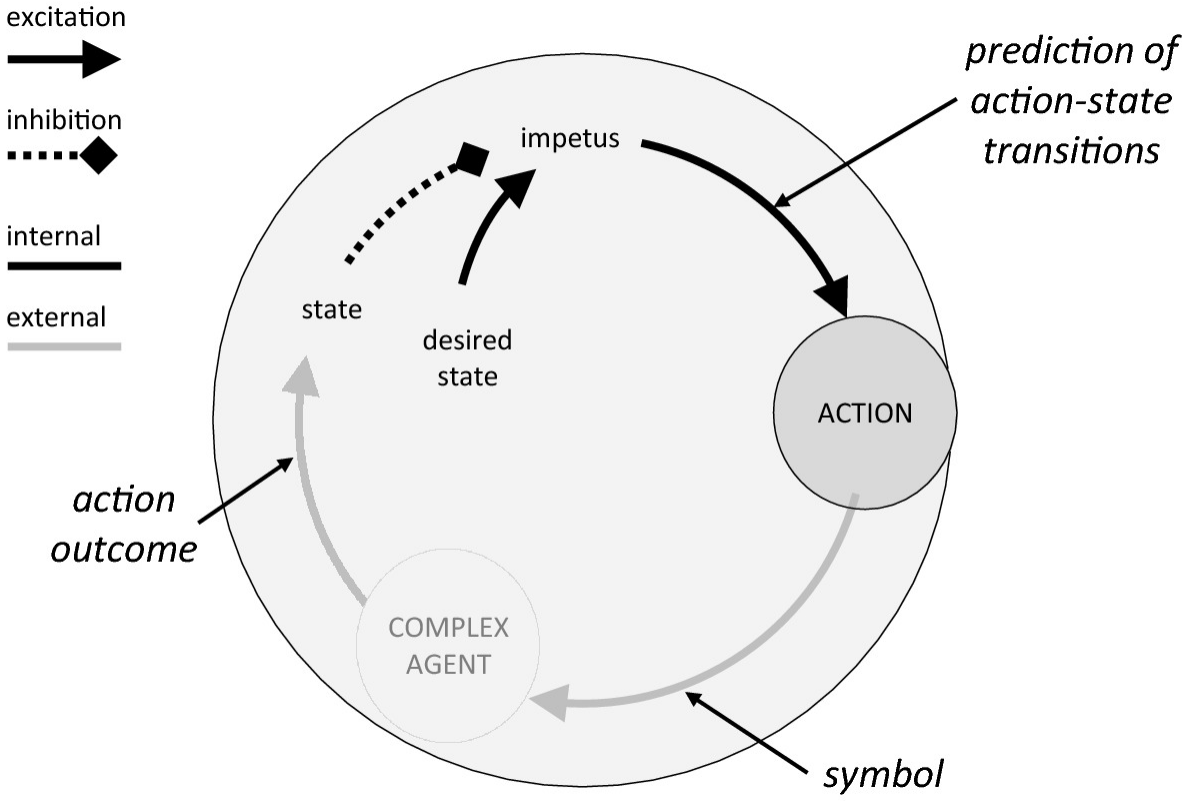


Fig. 24.4 Control through an external agent whose behavior is sophisticated but predictable. Here, the external agent can be relied upon to produce a desirable outcome in response to a simple symbolic gesture or utterance

Animals respond in complex but predictable ways to various stimuli. When a threatening posture is assumed by one crayfish, another will either back off or respond with its own threat posture. This establishes a domain of interaction between the two creatures where each can attempt to control the other into conceding submission. Often, no actual fighting needs to take place before the dominance hierarchy is achieved. It may be said that the dominant crayfish has successfully exerted control over its opponent. It has eliminated the impetus "threat by a rival" by exploiting the rival's predictable responses to its behavior.

Importantly, interactions between creatures are by their nature highly categorical. If you're controlling someone to approach or back away from you, you are not concerned with how they place their feet; all that matters is the resulting physical distance. Thus, communicative control naturally develops mechanisms providing to the receiving agent simplified "key stimulus" features that are compact and

symbolic, and their effectiveness is only contingent on whether they are obeyed. The mechanism by which a monkey can control another to back off may have originated with actual fighting and biting, but over time it was replaced with the simple gesture of baring one's teeth because this was just as effective in achieving control and did not risk physical injury.

In cooperative interactions, these kinds of control mechanisms can achieve very high levels of sophistication. For example, a helpless human infant has almost no control over its world, and cannot obtain food, find shelter, etc. However, it so happens that in the niche of human infants there exist highly sophisticated creatures that will happily do anything to satisfy that infant's needs. Better still, these creatures can be controlled through very simple symbolic utterances, such as crying. Initially, the symbol need not even be specific to any given need—the parents are smart enough to figure out what the problem is and how to deal with it, whether it involves providing milk or driving at high speed to a hospital. In other words, the behavior of parents is so sophisticated but so easy to control that human infants can survive with just a few simple symbolic gestures and utterances. Furthermore, because of the consistency of parental behavior, the infant can eventually fine-tune its utterances to satisfy increasingly specific needs. In fact, the parents will help with this, gradually distinguishing between different symbols that are agreed upon, within a given social group, to correspond to specific control goals. For an external observer, the interactions between the parents and the child might look like transmission of information, but their meaning lies not in the message that is transmitted but in the control dynamics that are established between the agents (Cisek, 1999; Tison & Poirier, 2021; Hendriks-Jansen, 1996). Along these lines, Barrett and Henzi (2005) suggest that what is sometimes described as cognition in primates comes not from the mechanisms within each animal's brain but through the dynamics of competitive and cooperative control within their social group.

Concluding Remarks

From an evolutionary perspective, the phrase “embodied cognition” gets things backwards. Embodiment is not merely a type of cognition; it is not just a tool in the representational toolbox of a computational process for building knowledge. It is the fundamental context within which things like knowledge evolved, millions of years after the major topological pieces of the vertebrate nervous system were already established. Behavior first emerged as an extension of metabolic control outside of the body, complementing the dynamics of the environment such that the entire organism-environment system flows toward desirable states. This is accomplished through negative feedback control, whereby actions are taken to reduce or eliminate the conditions (“impetus”) motivating those actions—including internal drives such as hunger and external conditions such as the presence of a predator. All animal behavior can be viewed within this context of interactive control, including social interactions such as vocal and gestural communication. In social animals, the interactions become incredibly complex, creating novel domains of control with their own “cultural affordances” (Ramstead et al., 2016) that can be used to improve one’s state (e.g., rising in a dominance hierarchy or social status). In this abstract domain, control is established through highly compact linguistic and gestural “symbols” that accomplish the high-level goals of persuasion and cooperation. Thus, even communication is a type of control. However, because so much of our life is concerned with that domain of human linguistic interaction, with its transmission of symbolic utterances, we are tempted to see its properties as the atoms of all behavior. And so, we’re led to describe the basic function of the brain as the reception of input signals that must be decoded by something called “perception”, assimilated into knowledge by something called “cognition”, and ultimately used to represent plans that are implemented by an “action” system. But those are just terms that we use to describe our own behavior. They are just another example of the compact symbols we use to persuade each other, and do not correspond to the biological organization of the nervous system produced by the long history of our evolution. In reality, embodied control is fundamental, and cognition is a special case.

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© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_25

25. Experiencing Embodied Cognition from the Outside

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Abstract

Embodied cognition has been put forth as an alternative to mainstream approaches to cognitive psychology, which supporters claim do not and cannot consider perception and action. Are depictions of cognitive psychology put forth by embodied cognition proponents accurate? To answer this question, we summarize foundational research in cognitive psychology and show that it addresses many of the issues that are considered significant in embodied approaches. We distinguish simple embodiment from radical embodiment and argue that the former is not fundamentally different from mainstream cognitive psychology because it falls within a worldview called mechanism. Radical embodiment is fundamentally different because it falls within the worldview of contextualism, of which the radical empiricism endorsed by Gibson and radical behaviorism advocated by Skinner are varieties. We argue that the incorporation of concepts from Gibson's ecological psychology within a representational approach leads to misleading claims and confusion. We conclude that researchers who espouse radical embodiment should accept all of its implications and researchers who endorse simple embodiment should accept that they are part of the same research enterprise as other cognitive psychologists.

Keywords Cognitive psychology – Ecological psychology – Experimental psychology – Radical embodiment

To appear in ***Embodied Psychology: Thinking, Feeling, and Acting***, Michael Robinson & Laura Thomas (Eds.).

Experiencing Embodied Cognition from the Outside

To situate work on "embodiment" in psychology, we thought it best to begin with documenting when the concept came into use and why. We focus this chapter on "embodied cognition", since that comprises the core of the arguments for embodiment. Entering the search term "embodied cognition" into the PsycINFO database on December 31, 2019, without selecting a field, yielded 2,039 entries. However, restricting the search to entries prior to and including the year 1989 yielded only two entries, both of which do not use the component terms in the specific sense of embodied cognition. Loosening the search to "embodiment", which is used in many different senses, yielded more entries prior to the 1990s, but they are mainly restricted to the physiological basis of cognition (McCulloch, 1965) and the field of linguistics (Lakoff, 1987). Restricting the search for "embodied cognition" to 1990–1999 resulted in 25 entries, including some formative journal articles and chapters. Thus, psychologists did not begin to embrace the concept until the 1990s. From that time to the present, the concept of embodied cognition has gained increasing popularity, with 261 entries in the years 2000–2009 and 1,750 entries from 2010 to 2019. These data indicate that the use of the term "embodied cognition" in psychology is mainly a twenty-first-century phenomenon.

Given that reference to "embodied cognition" originated in the 1990s and "took off" in the first decade of the twenty-first century, it is essential to understand what cognitive psychology was like at the time and the factors that led to embodiment being seen by its advocates as a necessary addition to the terminology. Published in the latter half of the 1990s, the edited book ***Creative Thought*** (Ward et al., 1997) includes three chapters advocating an embodied approach, and

provides a representative sample of the arguments for embodied cognition. The reasoning is described in the editors' introductory chapter (p. 20) as:

> ... there is also evidence that simply being human and existing in a particular body in a particular world matter to the nature of our cognitive representations and, hence, to our potential for creative functioning. This notion of embodied cognition manifests itself in the nature of our basic knowledge representation (Barsalou & Prinz), our mental models (Glenberg), and our metaphoric production and comprehension (Gibbs).

Barsalou and Prinz (1997) argued against amodal symbol systems proposed by some authors (e.g., Fodor, 1975; Pylyshyn, 1984) for which the symbols are not rooted in perceptual content. Gibbs (1997) stated more generally, "In contemporary psychology the mind is viewed as disembodied" (p. 353) and provided examples and evidence to show the embodied nature of concepts in language. Glenberg (1997) considered two possible bases for mental models constructed during language comprehension, one involving spatial representation and the other embodiment. He concluded that the former is inadequate and that an embodied account is necessary. The foundational rationale provided by these authors is that psychologists had not previously given sufficient consideration to embodiment, and a move in that direction was needed.

The claim made in these chapters—that cognitive psychologists have neglected action and the body—is also stated elsewhere in the embodied cognition literature. For example, Willems and Francken (2012, p. 1) describe "the traditional divide between cognition on the one hand and perception and action on the other". But this general assertion is debatable and necessitates investigation. Perusal of the reference sections for the three cited chapters from the Ward et al. (1997) book, and many other writings on the topic of embodied cognition, reveals an absence of consideration of major research lines in cognitive psychology that have been devoted to perception-action relations. Specifically, the perception, attention, and performance

tradition is overlooked. Much, but by no means all, of the research on these topics was published in the ***Journal of Experimental Psychology (JEP)*** when it was a single journal and in the ***Journal of Experimental Psychology: Human Perception and Performance*** (***JEP:HPP***) when ***JEP*** was split into four journals in 1975.

Note that this latter, major journal in experimental cognitive psychology was founded 15 years before the decade in which the term "embodiment" began to appear in the psychology literature. In his editorial at the beginning of the first issue of ***JEP:HPP***, the editor, Posner (1975), the prominent cognitive psychologist, stated, "The information-processing approach provides the opportunity to understand the mental operations that lead to and follow from the subjective experiences described in conscious reports and judgments" (p. 1). One might modify that statement nowadays to convey more clearly a reciprocal relationship, but the point is that considerable research was conducted from the earliest days of contemporary cognitive psychology that was embodied at least in the sense of considering perception and action as significant parts of human information processing. Yet, none of the three cited chapters from the Ward et al. (1997) book includes reference to the human perception and performance work published in ***JEP:HPP***.

These chapters illustrate that those aligning themselves with an embodied approach have tended to overlook relevant work conducted within cognitive psychology. Consequently, cognitive psychologists' consideration of action and the body has been mischaracterized. More seriously, we think that it has resulted in many research findings being interpreted in ways that are not justified by the data. One can ask whether this overlooking of relevant research in cognitive psychology might be because the research is seen as being of little value for informing the work of those who identify with embodied cognition. Or, might this reflect a general lack of awareness of the large, relevant body of literature within cognitive psychology? Regardless of the reason, if advocates of embodied cognition want to have a significant impact on other cognitive scientists who work in the areas of perception and action, they must situate their research accurately within the substantial body of knowledge on those topics. For purposes of moving the research of embodied psychologists forward, our chapter provides

a review of foundational work in cognitive psychology, discussion of views that have been advocated by embodied proponents, implications of accepting a radical form of embodiment, and dangers associated with adopting concepts from radical embodiment approaches and applying them to results from laboratory experiments using standard information-processing methods.

Foundations of Contemporary Cognitive Psychology

The view that cognition is situated has been around since the earliest contemporary cognitive psychology research coming out of World War II (Xiong & Proctor, 2018). Much of the research evolved from issues associated with aviation and other technological advances occurring during the war, with work conducted by individuals at the Medical Research Council Applied Psychology Unit in Great Britain (Reynolds & Tansey, 2003) and the Psychology Branch of the Army Air Force Aero Medical Laboratory in the U.S. (Roscoe, 1997). This research investigated, among other topics, problems of vigilance associated with tasks performed in situations where soldiers were on a vigil, problems associated with attention and response selection relating to tasks performed by aircraft pilots, and limitations in dual-task performance. For example, among the findings of his classic vigilance study, Mackworth (1948) linked perception and action, noting "… lapses in visual perception… become more frequent when the subject has recently responded to one visual signal and is not expecting another since he imagines the stimuli are few and far between" (p. 17). The research of this era not only spawned cognitive psychology, but also generated applied research on human factors engineering and, later, human–computer interaction.

Donald Broadbent's (1958) ground-breaking book on cognitive modeling, regarded as the first major theoretical endeavor in human information processing (Smith, 2001), is titled ***Perception and Communication***. Chapter 3 of Broadbent's book is "Verbal and Bodily Response", in which he examines dissociations between the two forms of response. In Chap. 11, "Recent Views on Skill", Broadbent examines explanations of the psychological refractory period effect (delay in

responding to the stimulus for a second task when it occurs shortly after that for the first task) and preferred control-display relationships.

Two years later, Miller et al. (1960) published ***Plans and the Structure of Behavior***. Their book relied heavily on cybernetic theory, which incorporates feedforward and feedback loops into analyses of control systems. Another significant book was Neisser's (1967) ***Cognitive Psychology***, which is regarded as the first general synthesis of the field and sufficiently influential to brand him the "father of cognitive psychology" (Hyman, 2012). Neisser focused on perception, attention, and memory, and distinguished between nonverbal codes (visual and auditory) and verbal codes. Although Neisser did not put much emphasis on action, he discussed the motor theory of speech perception, according to which speech is perceived through the production of incipient articulatory movements (see Galantucci et al., 2006, for a review). Neisser ultimately favored an analysis-by-synthesis view according to which the production occurs at a more central level than articulatory movements.

Fitts and Posner (1967) provided an overview of much of the research in human information processing through the mid-1960s in their book, ***Human Performance***:

> Since about 1950 the world has seen a tremendous growth in the sciences dealing with information. Of importance to psychologists has been the development of human-performance theory, which seeks an approach to the study of information processing within man's nervous system and communication between man and his environment (p. 5).

Note the emphasis on the nervous system and interactions with the environment. The longest chapter in the book (40 pages), at more than twice the length of any other chapter, is "Component Processes and Performance Capacities", with the major sections being Sensory Capacities, Perceptual Processes, Memory Processes, and Response Processes. Another chapter, "Human Capacities in Perceptual-Motor Skills", contains a discussion of many foundational studies, including Fitts's classic studies of response selection (stimulus–response compatibility; Fitts & Seeger, 1953) and movement execution (Fitts's

law for speed and accuracy of aimed movements; Fitts, 1954), which continue to have signi cant in uence in basic and applied cognitive psychology to this day. The chapter also discusses research on tracking tasks, for which participants must pursue a continuously changing track, as in driving, which dates back to Craik (1948).

A nal book worth noting is Haber's (1969) edited compendium of previously published journal articles, ***Information Processing Approaches to Visual Perception***. In the preface, Haber states, "I feel that the problems herein outlined, and the topics discussed, hold the principal operations for understanding the means by which human beings perceive, process, remember, and respond to visual stimulation" (p. v). The topics include the entire range of human information processing except for motor execution, which, as noted, received substantial coverage in Fitts and Posner's (1967) book.

The embodied cognition literature is replete with references to "the traditional" cognitive psychology or mind-as-computer approach (e.g., Fincher-Kiefer, 2019; Galetzka, 2017), often referencing Fodor (1983) and Pylyshyn (1980), as Barsalou and Prinz (1997) did, both of whom advocated extreme views of perceptual, cognitive, and motoric processes being modular and non-interacting. For example, Robbins and Aydede (2009, p. 4), stated,

> This focus on the sensorimotor basis of cognition puts pressure on a traditional conception of cognitive architecture. According to what Hurley (1998) calls the "sandwich model," processing in the low-level peripheral systems responsible for sensing and acting is strictly segregated from processing in the high-level central systems responsible for thinking, and central processing operates over amodal representations. On the embodied view, the classical picture of the mind is fundamentally awed.

Yet, even before the concept of embodiment appeared in the psychology literature, George A. Miller (1986), a patriarch of cognitive psychology, made clear that the views of Fodor and Pylyshyn, and the idea of strict segregation of processing, do not comport with those of most cognitive scientists. Speci cally, Miller stated,

> Experimental psychologists have argued only for a kind of weak decomposability, a claim that circumstances can be arranged in such a way that one process can be studied while others remain invariant. Apparently discouraged by this approach, Pylyshyn (1980) has called for strong decomposability, for modules that cannot interact. To say that it is possible for systems not to interact [the view of experimental psychologists] is very different from saying that their interaction is not possible. (pp. 292–293)

After several further paragraphs discussing Pylyshyn's and Fodor's views, Miller concluded, "Unfortunately, however, they do not yield components of any value for the analysis of those mental processes that most cognitive scientists find most interesting" (p. 293). In short, contrary to modern-day depictions (e.g., Sadoski, 2018), most cognitive scientists did not hold and have never held the "traditional" views often attributed to them in the embodied cognition literature.

To summarize, considerable research on both basic and applied aspects of perception, attention, cognition, and action was conducted prior to embodied cognition being promoted as a novel approach. The "traditional" view attributed to cognitive psychologists/scientists was not ever held by the majority of cognitive psychologists, who studied the whole gamut of human information processing. If cognitive psychologists/scientists never widely endorsed the "fundamentally flawed" cognitive architecture attributed to them, the question becomes, how does the embodied cognition approach compare to and differ from that of mainstream researchers? We provide our answer to that question in the following sections.

Embodiment Five Ways

To evaluate alternative interpretations of embodied cognition, it is necessary to first operationalize what is meant when cognition is referred to as embodied. If one adopts an "embodied" view, it might be contended that the current or potential state of a person's body affects semantic representations or, in a similar manner, that attention might be guided by body-specific information, and so on. However, this is a

major oversimpli cation, and operationalizing embodied cognition is not an entirely straightforward task as there exists a spectrum of variations to which individuals may be referring when employing the term (Wilson, 2002). This spectrum can be considered to range from "simple" embodiment in which the importance of context is emphasized to "radical" embodiment in which the notion of mental representations is rejected in favor of a type of cognition that extends into the environment (Goldinger et al., 2016; Mahon, 2015).

Wilson (2002) distinguished six views of embodied cognition that encompass many of the ways in which the term is used: "(1) cognition is situated; (2) cognition is time-pressured; (3) we off-load cognitive work onto the environment; (4) the environment is part of the cognitive system; (5) cognition is for action; (6) off line cognition is body based" (p. 625). Of these, only the fourth view is radical in the sense of proposing a worldview that is inconsistent with that adopted in contemporary cognitive psychology, where the human information-processing approach predominates. Consequently, in this section, we discuss only the other five views of embodiment, and we devote the following section to Wilson's fourth view.

Wilson (2002) emphasized conceptual, theoretical, and empirical issues associated with each of the views she identi ied, beginning her article with the statement,

> Traditionally, the various branches of cognitive science have viewed the mind as an abstract information processor, whose connections to the outside world were of little theoretical importance. Perceptual and motor systems, though reasonable objects of inquiry in their own right, were not considered relevant to understanding 'central' cognitive processes. (p. 625)

Note the similarity of this statement to Gibbs's (1997) statement cited earlier, the major tenets with which we disagreed. In contrast to Wilson, our focus is on whether cognitive psychology/science really neglected embodiment as characterized in those statements and similar ones found in the embodied psychology literature. As might be evident from our review of the foundations of contemporary cognitive

psychology in the previous section, we argue against the position that there was neglect, at least in the field as a whole.

Cognition Is Situated

According to Wilson (2002), "A cornerstone of the embodied cognition literature is the claim that cognition is a situated activity" (p. 626). But hardly anyone would disagree with the statement that cognition is situated. People perceive, think, and act in various situations and contexts, whether those are lecturing to students, reading a novel at home, interacting with a computer, driving a car, and so on. Although much research conducted in cognitive psychology is basic, laboratory research, the concepts can be applied to specific situations. Indeed, as noted, much of contemporary cognitive psychology was grounded in applied research from World War II involving interactions of pilots with aircraft, operators with radar and sonar systems, and soldiers with other technologies that were new at the time. Division 21 of APA, Applied Experimental and Engineering Psychology, founded in 1956, is devoted specifically to use-inspired research aimed at providing guidance for specific situations.

Within engineering psychology and human factors, the concept and measurement of ***situation awareness***, one of the major tools in the past 25 years, came directly from research on perception and cognition. Endsley (1988a, 1988b) developed the concept and a technique for measuring it in the context of the assessment of pilot performance and evaluation of alternative interface designs. She provided the definition of situation awareness that is still the most widely cited one: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (1988a, p. 792). Although Endsley's degrees are in the industrial engineering side of human factors, she based her analysis on a human information-processing model, noting:

> A great deal of research in psychology has been devoted to more general aspects of human cognition, such as information processing, memory structures, attention and decision making. In combination, the mechanisms of short term sensory memory,

> perception, working memory and long term memory form the basic structures for pilot situation awareness. (1988b, p. 98)

Note that Endsley's trailblazing research took place prior to the 1990s, when claims began to be made that cognitive scientists were not taking into account the situational nature of cognition.

So, does the view that cognition is situated have anything new to offer? Tversky (2009) started her chapter in Robbins and Aydede's (2009) ***Cambridge Handbook of Situated Cognition*** stating, "What does it mean to say that cognition is situated? Like many interesting questions, this one has many answers, probably at least one for every chapter in this volume" (p. 201). That seems to be as true today for various researchers as it was in 2009, and it is similar to the comments made when researchers examine the question "What does it mean to say that cognition is embodied?" Moreover, the relation between embodied cognition and situated cognition is circular. Whereas Wilson (2002) emphasizes cognition being situated as a view of embodiment, Robbins and Aydede list the embodied mind as the first of three theses that are central to the concept of situated cognition.

In its most general sense, saying that cognition is situated means that specific tasks and situations must be understood in order to apply more fundamental knowledge of humans to those tasks and situations. This is captured in the definition that Elsbach et al. (2005) provided for the area of organizational science: "Proponents of situated cognition... argue that cognition exists in the interaction of perceivers' minds (schema) and their environment (context). That is, situated cognition is thinking that is embedded in the context in which it occurs" (p. 422). It is difficult to conceive of any cognitive psychologist who would disagree with this characterization of cognition taking part in specific environmental contexts.

Cognition Is Time-Pressured

That cognition is time-pressured seems hardly to be a distinguishing characteristic of embodied cognition. Reaction-time studies, in which people are instructed to respond as quickly as possible to a stimulus event, have been used since the earliest days of psychological research (Donders, 1868/1969). Such studies were conducted so frequently

from the 1950s onward that Lachman et al. (1975, p. vi) christened reaction time the measure of the information-processing paradigm. Also, speed of responding is analyzed in investigations of speed-accuracy tradeoffs (Dambacher & Hübner, 2013; Rank & Di Luca, 2015), in many cases utilizing sequential sampling models of human performance (Ulrich et al., 2015).

Time pressure is also studied as a stressor in time-limited behaviors. For example, Wirth and Carbon (2017) found that face-matching performance in a passport-check scenario was impaired under time pressure. Moreover, Rattat et al. (2018) had participants solve mazes in conditions with and without time pressure. Both verbal time estimation and time production tasks showed that durations were judged longer when there was time pressure than when there was not, and the results were interpreted in terms of scalar expectancy theory (Gibbon et al., 1984), a popular theory of timing. In sum, the notion that cognition is time-pressured in the embodied cognition approach does not contribute much, if anything, beyond what has been known and studied previously in cognition.

People Off-Load Cognitive Work onto the Environment

Off-loading cognitive work onto the environment does not uniquely define embodied cognition, either. As anyone who goes to the grocery store can appreciate, people routinely use shopping lists as memory aids to assist with their purchases. One of the central themes in cognitive psychology is that attention and working memory capacity are limited and, consequently, considerable effort is required to use their resources (Unsworth & Robison, 2020). Accurate retrieval of information from long-term memory is also limited and relies in some cases on effortful retrieval strategies (Unsworth et al., 2012). So, from an information-processing perspective, it makes sense that people will offload cognitive work whenever possible.

Indeed, who would question that people use calculators and computers to execute computations that would overload their cognitive capacities, cell phones, and email lists as memory aids, and medication organizers to help determine when and what medications to ingest? Such offloading is evident in the research on prospective memory. For instance, Gilbert (2015) studied strategic offloading of

intentions to the external environment in a web-based task in which participants had to hold intentions for short time periods. They were allowed to externalize those intentions by creating a reminder. Setting external reminders was found to improve the performance of the participants who did so, and, critically the reminders were used more often when memory load or likelihood of distraction was high. Concepts from cognitive psychology are useful for understanding offloading, and researchers do not have to endorse embodied cognition to explain how, why, and when people use cognitive offloading.

Cognition Is for Action

As described in the section "Foundations of Contemporary Cognitive Psychology", the general idea that perception and cognition are closely related to action has been prevalent in the human performance tradition since the earliest days of the field. For example, an immense body of research on stimulus–response compatibility effects of various types has been conducted from the 1950s to the present (Hommel & Prinz, 1997; Proctor & Reeve, 1990; Proctor & Vu, 2006). This research specifically involves the processes that operate on stimulus information to generate responses in a variety of tasks. Over the past two decades, research has also investigated action-effect (or response-effect) compatibility, which examines the relation between executed responses and their perceptual consequences (Janczyk & Lerche, 2019; Kunde, 2001).

Moreover, the information-processing approach has proved to be profitable for investigating many issues in human motor control and learning (Stelmach, 1978). As a recent example, Roberts et al. (2017) examined what they called "early visual information processing for late limb-target control" (p. 384). Specifically, they concluded, "the visual information processing demands imposed by reacted aims can be adapted by integrating early feedforward information for limb-target control" (p. 384). On a personal level, the first author of this chapter enjoyed a successful research collaboration of approximately 10 years with T. Gilmour Reeve, a kinesiologist trained in the area of motor control and learning. This research integrated our respective knowledge of cognition and motor control (Proctor et al., 1992).

Off‐line Cognition Is Body Based

The term "off‐line cognition" seems to be used primarily, if not solely, by advocates of embodied cognition. It is intended to convey the idea that cognition when not perceiving and acting is based on the same mechanisms that are involved when perceiving and acting. It is difficult to know exactly what to make of the claim that off-line cognition is body-based. The concepts of mental imagery/perceptual representations and motor plans have been around within cognitive psychology and psychology more generally before the current era.

Beginning in 1963 and 1965, Allan Paivio's dual-coding theory, in which visual image codes are distinguished from verbal codes, had a significant influence on research in human learning and memory. In Paivio's (1991) words,

> Dual coding theory (DCT) evolved from specific experiments on the role of imagery in associative learning (Paivio, 1963, 1965). I recognized then that the approach and results departed from the verbal learning and memory tradition of that period, but could not foresee how quickly the research would expand and lead to a general theory of memory and cognition. (p. 256)

Stephen Kosslyn and colleagues began investigating and making a case for the perceptual basis of mental imagery in the late 1970s. In fact, PsycINFO shows 77 entries with "imagery" in the title authored by Kosslyn as of April 2020. Of interest is that Kosslyn et al. (1979) in an early ***Behavioral and Brain Sciences*** article mention "embodied" with respect to the embodiment of their theory in computer simulations and other similar ways, but not in terms of embodied cognition. Likewise, in the area of motor learning, the topic of mental practice has been investigated for years, with the exact nature of the benefits examined in some detail (Hinshaw, 1991; Richardson, 1967a, 1967b).

No one would seem to disagree with the idea that some cognition in the absence of perception and action can be, and is, body-based. However, the proposition that all off‐line cognition is body-based (Barsalou, 2010) is much more debatable.

Summary

Cognitive psychologists would readily proffer that cognition is context dependent, temporal, and action oriented, and, under certain circumstances, may be body-based or offloaded into the environment. None of the five views of embodied cognition described in this section seems to distinguish embodied cognition fundamentally from other approaches to cognitive psychology. Researchers who adopt these views by and large conduct research similar to that performed by cognitive psychologists in general, with perhaps more emphasis on particular aspects of human cognition, such as studying situations outside of the lab. From our perspective, advocates of embodied cognition represented by these views are engaged in empirical research within the same worldview as other psychologists and differ only in the hypotheses they tend to favor (see the section, “Radical Empiricism and Radical Behaviorism”).

Radical Embodiment: The Environment Is Part of the Cognitive System

The five views on embodied cognition discussed in the previous section are not fundamentally distinct from those adopted by other cognitive psychologists. They can be labeled as falling within the category of simple embodiment, for which Lindblom (2015, p. 4) has said, "In simple embodiment, the traditional foundation of cognitive science (i.e., information-processing and computationalism) is preserved, and the nature of embodiment is merely considered a constraint of the 'inner' organization and processing". She contrasts this position with that of radical embodiment, which she endorses: "Radical embodiment, on the other hand, goes much further and treats the facts of embodiment as a fundamental shift in the explanation of cognition that is 'profoundly altering the subject matter and theoretical framework of cognitive science' (Clark, 1999, p. 348)" (p. 4).

Radical embodiment corresponds with the fourth view described by Wilson (2002), according to which the environment is an inseparable part of the cognitive system. This view cannot be reconciled with the approach taken by most cognitive psychologists and cognitive scientists. Wilson makes this view explicit, stating that in the radical embodiment view, "the mind alone is not a meaningful unit of analysis" (p. 626). Obviously, this view differs greatly from that of most psychologists—cognitive, social, or otherwise—who study the mind and behavior as meaningful units of analysis. But, Wilson goes on to make what we consider to be an essential point, "In fact, relatively few theorists appear to hold consistently to this position in its strong form. Nevertheless, an attraction to something like this claim permeates the literatures on embodied and situated cognition" (p. 630). In other words, although embodied theorists "talk the talk" by endorsing the radical embodied view, few actually "walk the walk". Because the radical claim that the mind is a meaningless unit of analysis permeates the literature but is not strictly adhered to, implications of the claim and why there is often not strict adherence to it need to be examined.

Gibson's Ecological Psychology

This final view can be credited to several sources, but in psychology, Gibson's (1979) ecological approach to perception and action is often cited in this regard (e.g., Garbarini & Adenzanto, 2004). Gibson's approach is markedly different from the information-processing approach to perception, cognition, and action. To understand Gibson's ecological approach, it is useful to first discuss what led to its creation. Among other factors, the approach was rooted in his frustration with mainstream approaches to perception based on research conducted in laboratory settings without the environmental cues available in the world (e.g., dynamic depth cues). In his development of the ecological approach to visual perception, Gibson emphasized that perception is first and foremost for purposes of guiding action in the natural environment. As Garbarini and Adenzanto (2004) noted, "The central point of Gibson's theory was his explicit refusal of the dichotomy between action and perception and the underlying dualism between physical and mental capacities" (p. 101). More importantly, the framework Gibson developed refuted the necessity of mental representations and advocated for direct perception instead. To dovetail off the importance of unmediated perception, he contended that affordances (which specify actions) exist within the environment and can be directly perceived. The direct perception and the affordance concepts make up the cornerstone of Gibson's approach to perception and action.

Gibson's approach has garnered much support and generated its own subfield, ecological psychology (Lobo et al., 2018). Researchers in this tradition choose to employ methods that require users to make judgments about and interact with ecological settings representative of the world around them. It is essential to highlight again that within ecological psychology, there is an emphasis on the context in which individuals find themselves and the dynamic relationships that exist between humans and the natural environment, without assuming mediation by mental representations. Methods may include, for example, studying perception during a single instance in which individuals perform certain actions while carrying backpacks of various sizes (Ishak et al., 2019) or across several instances to determine how perception changes as pregnancy progresses (Franchak & Adolph, 2014).

Despite the divergence of Gibson's views from those held by many embodied psychologists, which rely on mental representations, Gibson has nonetheless become "one of the heroes of embodied cognitive science" (Chemero, 2013; p. 146). But, what does it mean to adopt Gibson's line of thinking? If one were to elect to adopt the highly contextual view of cognition in the spirit of ecological psychology, methods and measures far removed from typical, controlled laboratory settings would be required. Here, the prototypical experimental psychologist, who has the goal of isolating causal mechanisms, would, in common parlance, exit stage left. After all, experimental psychology is rooted in the systematic manipulation and control of variables to isolate determinants of human behavior, not in the study of a multitude of factors that are constantly in flux.

Radical Empiricism and Radical Behaviorism

What differentiates Gibson from most other psychologists is his adoption of radical empiricism (Gibson, 1967; Heft, 2001), which is a close relative of Skinner's radical behaviorism (Morgan, 2018). Gibson denied the need for mental representations, as highlighted by Lobo et al. (2018), who emphasize "The ecological approach rejected the inferential and representational commitment of cognitivism..." (p. 2). Skinner did as well, stating of a theory of behavior, "At no time will the theory generate terms which refer to a different subject matter, to mental states, ... or neurons" (Skinner, 1947/1961, p. 233). As put by Ahearn (2010) more recently, "Rather than place causal status in hypothetical entities or constructs, Skinner's radical behaviorism attempted to demonstrate orderly relations between behavior and environment".

Given that radical empiricism and radical behaviorism are minority views in psychology, it is perhaps not unexpected that advocates of both have latched onto the embodied cognition movement to stake claims. Lobo et al. (2018) begin the abstract of their article on the history and philosophy of ecological psychology with the statement, "Ecological Psychology is an embodied, situated, and non-representational approach pioneered by Gibson and Gibson" (p. 1). Likewise, Morgan (2018) noted that this view espoused by some embodied theorists "represents, in fact, the essential feature of the

theoretical writings of both Gibson and Skinner. Contemporary work in embodiment is remarkable in its resemblance to the tenor and explanatory language of these two pioneers" (pp. 2–3). As noted, the similarity of the approaches of Gibson and Skinner is due to their adoption of radical empiricism and radical behaviorism, respectively, which explain perception, action, and behavior without invoking mental representations. Both can be classified as forms of a world view called contextualism (Hoffman & Nead, 1983; Morris, 1988), also sometimes called pragmatism, which is distinct from that known as mechanism (Pepper, 1942), to which most psychological scientists subscribe (Capaldi & Proctor, 1999), see Fig. 25.1.

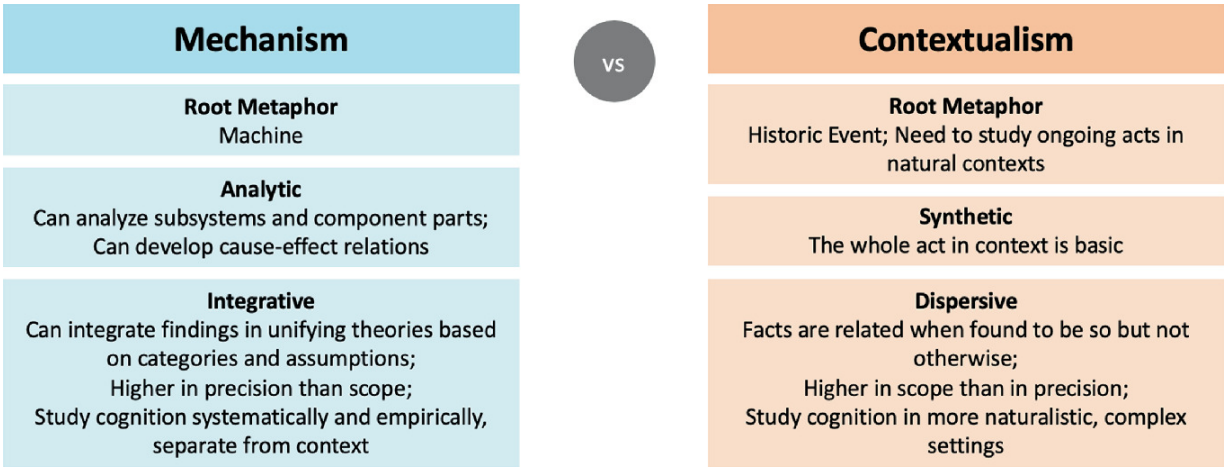


Fig. 25.1 Characteristics of mechanism and contextualism

For mechanism the primary, or root, metaphor is a machine, which can be analyzed in terms of its subsystems and components. According to Pepper (1942), mechanism is analytic but with integrative theories. Because scientists for the most part adopt an approach of analyzing phenomena of interest through controlled experiments and organizing the obtained findings in integrative theories, it is not too remarkable that Pepper would say, "Mechanism has for several generations been particularly congenial to scientists" (p. 110). For contextualism, in contrast, the root metaphor is the historic event, or act in context. In Pepper's words,

> To give instances of this root metaphor with the minimum risk of understanding, we should use only verbs. It is doing, and

> enduring, and enjoying, making a boat, running a race, … removing an obstacle, … re-creating a poem. These acts or events are all intrinsically complex, composed of interconnected activities with continuously changing patterns. They are like incidents in the plot of a novel or drama. They are literally the incidents of life. (p. 233)

Accordingly, Pepper describes contextualism as synthetic with dispersive theories.

What this distinction should alert readers to is that if a researcher truly adopts the view that "the environment is part of the cognitive system", that means that the researcher is aligning herself or himself with a worldview that is distinct from that subscribed to by most psychologists. In other words, it is a drastic shift that involves adopting a radical empiricist (Gibson) or radical behaviorist (Skinner) philosophy that is engaged in "a different game" than that in which most cognitive and social psychologists are engaged. The researcher must commit to dispensing with much of the experimental and analytic logic used by psychologists to understand cognition and behavior. This commitment is one that most cognitive and social psychologists would not be willing to make. Moreover, Wilson's comment to the effect that few embodied psychologists hold to the claim that the mind alone is a meaningless unit of analysis but "this claim permeates the literatures on embodied and situated cognition" implies that many embodied psychologists do not see that commitment as viable, either. Stated more strongly, adopting radical embodiment places a researcher well outside of the mainstream of cognitive psychology and psychology in general.

Combining Cognitive Psychology (Mechanism) with Ecological Psychology (Contextualism)

Since mechanism is analytic with integrative theories, and contextualism is synthetic with dispersive theories, each worldview is strong where the other is weak. Pepper (1942) noted that consequently there is a propensity for individuals to attempt to combine mechanism and contextualism with the intent of producing a more complete

theoretical system. So, the question can be asked, can gains be made by merging concepts from a contextualistic worldview, like Gibson's (1979) ecological psychology, with a mechanistic worldview, like that of cognitive psychology/information processing? Pepper's answer, which seems accurate, is negative: "Yet, mixed, the two sets of categories do not work happily, and the damage they do to each other's interpretations does not seem to me in any way to compensate for an added richness" (p. 147). Put differently, concepts lose much of their essential meaning when extracted from one worldview and used in another.

Attempts are made periodically within psychology to combine contextualism and mechanism. For example, De Houwer et al. (2017) proposed a functional-cognitive framework combining radical empiricism with cognitive psychology. Of interest in the present case is combining concepts from the radical embodied approach of ecological psychology with the concepts and methods of cognitive psychology, as has become commonplace for the study of affordances (e.g., Reed et al., 2010; Weser & Proffitt, 2019). We illustrate the pitfalls of doing so with a study by Tucker and Ellis (1998), cited 1236 times in Google Scholar as of 12–31-2019, which invoked the concept of grasping affordance to explain variants of stimulus–response compatibility effects obtained in choice reaction tasks. Tucker and Ellis had participants make keypresses with the left and right index fingers to images of objects with graspable handles (e.g., a frying pan) presented on a screen, with the handle oriented to the left or right. One keypress was to be made if the pan was upright and another if it was inverted. The main result was that responses were faster when the handle location corresponded with the response location than when it did not. Tucker and Ellis attributed this correspondence effect to a grasping affordance, for which the handle automatically produced motor activation of the hand corresponding to the handle side. This activation was presumed to facilitate the keypress when that response was the one to make based on the upright/inverted distinction and interference when it was not.

There are several points to make about applying the concept of affordance to this experiment. First, the experiment was conducted in a non-ecological setting to which Gibson's ecological theory is not applicable. The study was run in an artificial laboratory setting with

arbitrarily assigned keypress responses using a variation of a stimulus–response compatibility task (in this case, a "Simon" task for which handle location was task-irrelevant). Such tasks have been used for many years in cognitive psychology to study response selection (Lu & Proctor, 1995). Second, because the concept of affordance as developed by Gibson was inapplicable, the use of the concept in this situation required conversion to a representational account of affordances, which Tucker and Ellis (1998, p. 833) acknowledged.

A third point is that representational accounts of compatibility effects have been prevalent for years, but the evidence has largely pointed to spatial coding of stimulus and response locations as the critical factor (e.g., Umiltà & Nicoletti, 1990). To their credit, Tucker and Ellis (1998) did conduct an experiment intended to provide evidence against a spatial coding account of their results by having participants perform the task with two fingers on the same hand. However, despite obtaining ambiguous results and having several confounding factors that differentiated the between-hand and within-hand response conditions (e.g., separated vs. adjacent keys), they attributed their handle-correspondence effect to grasping actions afforded by the stimuli.

A fourth point is that in the statement acknowledging that their explanation was representational, Tucker and Ellis (1998) implicitly associated their account with ecological psychology: "Although this is a representational account of affordances, and therefore very different from the use of the term in the ecological sense, it nonetheless has its basis in a similar emphasis of the intimate link between perception and action" (p. 833). This implicit association was made despite the fact that perception and action were no more intimately related in their study than in the similar studies conducted routinely in cognitive psychology. This mismatch between Gibson's use of the term affordance and Tucker and Ellis's use has engendered considerable confusion (Chong & Proctor, 2020). Numerous studies have been conducted investigating "affordance compatibility effects" with keypresses (e.g., Pappas, 2014; Tipper et al., 2006), even though evidence has repeatedly shown that the effects are mainly, if not entirely, variants of spatial compatibility effects due to spatial

properties of the stimuli in relation to the responses (Masson, 2018; Proctor & Miles, 2014).

The mischaracterization of evidence as support for grasping affordance is propagated by proponents of embodied cognition. For example, Caligiore et al. (2010) stated with regard to spatial coding, "This account faces the difficulty of explaining why abstract codes related to objects automatically activate spatial components of responses (Tucker & Ellis, 1998)" (p. 1208). More recently, Barsalou (2016) cited Tucker and Ellis's study as evidence that "cognitive states often produced related bodily states. When people perceive tools, for example, their motor systems anticipate the actions associated with object affordances (Caligiore et al., 2010; Tucker & Ellis, 1998)" (p. 13). Masson (2018) stated emphatically that detailed evaluation of the evidence does not support such conclusions: "One can quite easily mistake an attentional effect based on spatial correspondence for evocation of a limb-specific action representation (see also Phillips & Ward, 2002)" (p. 222). The study cited by Masson is one in which the handle-correspondence effect was obtained with left and right foot-press responses, which are unrelated to grasping.

The interpretation of handle-correspondence effects in terms of grasping affordances provides a good illustration of Pepper's (1942) point that mixing the categories from the distinct worldviews of mechanism and contextualism does not work well and results in confusion. In the case of Gibson's ecological psychology and cognitive psychology, when attempts are made to blend together tenets from ecological psychology (e.g., affordance) with others of which Gibson was a vocal opponent (e.g., mental representations), what results is a haphazard psychology. If advocates of embodiment want to adopt radical empiricism, they should do so whole-heartedly and not just choose aspects that are to their liking while ignoring others that are not.

Additionally, and more importantly, the issue of handle-correspondence effects is one that can be investigated empirically. There are several ways to approach the problem of the conditions under which the potential for grasping a manipulable object may result in motor activation that affects keypress responses. Various efforts, for instance, have been directed at determining whether similar

performance patterns are observed when responses are made with an individual's feet (e.g., Phillips & Ward, 2002; Symes et al., 2005) and with non-manipulable objects (e.g., Anderson et al., 2002). If automatic activation of a grasping action is behind the observed performance, different result patterns should be found for dissimilar effectors and objects. However, this outcome has not typically been obtained. Tellingly, in his recent book, ***Bodies and Other Objects: The Sensorimotor Foundations of Cognition,*** which Anna Borghi describes on the cover as "setting the agenda for embodied cognitive (neuro)science in the future", Ellis (2018) described Tucker and Ellis's (1998) study and others from their lab as evidence for a grasping affordance motor activation, without mentioning the numerous findings that have called the affordance account into question.

As a final note, prior to interpreting results with new concepts counter to what is known, researchers should think skeptically about their possible interpretation. That is, they should consider alternative explanations systematically, which is a difficult but necessary task that needs to be undertaken to produce robust research. Consider, as an additional example, work on a hand proximity effect for which it was shown that placing the hands around a target letter reduces the interference produced by incongruent flanking stimuli outside of the hand space (Davoli & Brockmole, 2012). The authors proposed that this result was due to the palms of the hands acting as a sort of attentional spotlight whereby stimuli presented between the palms receive an attentional boost compared to stimuli outside of this spotlight. Similar to the handle-correspondence effect described earlier, as a researcher, one must do more than a cursory consideration of alternative causes for the results. Subsequent studies have demonstrated that wooden blocks and virtual barriers produce similar findings, which questions whether the palms of the hands are particularly special after all (Murchison & Proctor, 2015; Schneider, 2017). Although researchers have suggested that sample sizes be increased to allow for detection of particular embodied effects (Skulmowski & Rey, 2018), we argue that suitable experimental design and control conditions, and knowledge of related research, are more important.

Research on hand proximity that has been taken as evidence for a trade-off between sensitivity for information related to executing a grasping action as opposed to less action-oriented information seems similarly problematic. Gozli et al. (2012) initially made the claim based on experiments showing that holding the hands at the sides of a computer monitor (rather than in the lap) increased performance of a temporal-gap detection task and decreased performance on a spatial-gap detection task, even though these tasks and hand placements differed in many ways. Bush and Vecera (2014) replicated the effects with the two hands placed at the monitor sides but obtained the opposite results when only a single hand (left or right) was at the monitor side. This led to the ad hoc suggestion that "visual attention is focused on the graspable space for a single hand, and expanded when two hands frame an area of the visual field" (p. 232). Using a more complex procedure of judging whether successive displays with colored lines of different orientations matched, Kelly and Brockmole (2014) found that placing the hands at the monitor side decreased accuracy of discrimination for color changes but increased it for orientation changes.

Thomas (2015) described the near-hands placement used in the prior studies as using power-grasp postures. She explicitly manipulated power-grasp and precision-grasp postures for hands placed at the monitor sides. Whereas the former facilitated performance of a global motion-perception task, the latter facilitated the performance of a global form-perception task. Her conclusion was that "the visual system weights processing on the basis of an observer's current affordances for specific actions: Fast and forceful power grasps enhance temporal sensitivity, whereas detail-oriented precision grasps enhance spatial sensitivity" (p. 625). These conclusions were linked to the idea that the power grasp increased the weighting of the magnocellular pathway, but the precision grasp increased the weighting of the parvocellular pathway. There are many issues associated with invoking the concept of affordance to explain experimental results in artificial laboratory settings (Chong & Proctor, 2020). A major concern here is that the concept of affordance implies a direct influence of the motor system on perception, whereas the tasks involve judgments and response selection, which are more likely the

source of the results. Thomas (2017) showed that practice with the hands in unnatural postures engaging in power and precision grasps with the backs of the hands yielded similar results based on placements of the backs of the hands. She correctly noted that those results suggest that “visual biases are more malleable than this standard pathways hypothesis suggests” (p. 130), yet she still gave a possible explanation in terms of the magnocellular and parvocellular pathways and attributed the effects to perception.

The authors of the previous five studies framed their task differences in terms of the distinction between the magnocellular and parvocellular visual pathways, and provided interpretations of their results at least partially within that framework. That this mélange of results can be incorporated so facilely into the two visual pathways framework should alert advocates of embodied perception and cognition to be wary of such explanations. This point was made many years ago by the psychobiologist Uttal (1971) in his aptly titled article, “The Psychobiological Silly Season-or-What Happens when Neurophysiological Data become Psychological Theories”.

To conclude this section, it is necessary to reiterate three interlinked ideas. First, there is nothing inherently wrong or inferior in approaching human behavior through different lenses or worldviews. Second, in embracing one approach over another, one must understand the essential underlying commitments in order to maintain the integrity of the favored approach. Advocating one (radical embodiment) while practicing the other (simple embodiment) is misleading, and concepts from one worldview should not be incorporated into another. Third, regardless of the approach that a researcher adopts, taking into account the full body of knowledge in a topic area is essential to situate the research findings appropriately.

Conclusion

We presented evidence that, from the outset of contemporary cognitive psychology, the field as a whole has not, in fact, overlooked perception and action, contrary to common depictions in the literature. Indeed, these topics have been studied in a holistic approach to human performance. We argued that most views of embodied cognition are

variants of what other researchers are studying, which means that most embodied accounts should be seen as hypotheses to be tested in competition with other hypotheses and not as a distinct paradigm. We agreed that radical embodiment is within a different worldview than cognitive psychology, that in which ecological psychology and behavior analysis reside, which denies a role for mental representation. We pointed out what we think are hazards of researchers trying to take concepts from the radical embodied perspective and implement them in more standard cognitive psychology experiments. We contend that the embodied cognition perspective in its less radical iterations is not fundamentally distinct from other approaches and that acceptance of embodied explanations without proper evidence can have untoward consequences for the field.

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M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_26

26. The Future of Embodiment Research: Conceptual Themes, Theoretical Tools, and Remaining Challenges

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Abstract
Research on embodiment suffers from the lack of a shared theoretical and conceptual basis, so that it seems unlikely that all research sailing under the embodiment flag is actually targeting comparable questions and phenomena. A better organization of the field is, therefore, necessary to make progress. This will require trading the often-metaphorical interpretations of available findings for systematic predictions derived from a to-be-developed theoretical framework. This chapter discusses some of the major themes driving the embodied cognition movement and the degree to which they imply that human cognition is indeed embodied. As a theoretical framework to organize efforts to address these themes, the theory of event coding (TEC) is suggested, which provides a sufficiently rich theoretical and conceptual toolbox to systematically structure theorizing and studying,

and eventually improve our understanding of embodied cognition. The chapter concludes with a brief list of important challenges that remain to be tackled, including more specific, mechanistic theorizing about the representations underlying embodied cognition and the processes operating on them.

Keywords Embodiment – Theory – Theory of event coding – Mechanism

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Like many other new theoretical approaches, the embodiment movement, as I will call the total of approaches interested in embodied cognition in a broader sense, is a counter-reaction. What unites most members of the embodiment movement is the rejection of what has been captured by the term GOFAI—good old-fashioned artificial intelligence (Haugeland, 1985). What is attributed to the theoretical attitude that this term refers to is the assumption that human intelligence emerges from the mental manipulation of symbolic, amodal representations. If this were the case, as GOFAI claims, there would not necessarily be anything special about ***human*** intelligence, which in fact could be perfectly mimicked by symbol-manipulation operations in artificial systems, like computers or robots. Hence, artificial intelligence would be indistinguishable from natural intelligence, which is the key idea that led to the development of the Turing test (Turing, 1950). It is fair to say that the members of the embodiment movement are united in rejecting this symbol-manipulation approach as a sufficient theoretical basis for understanding human cognition.

What also unites the members of the embodiment movement is some theoretical reliance on the human body and/or the actions it is involved in. The details of this reliance are very diverse however: some consider body and action as the purpose of cognition, some as the vehicle or tool to generate cognition, some as a kind of modality or source of information, and some as a medium to generate internal simulations. The reasons for this diversity are that different members of the embodiment movement have counter-reacted to rather different developments in sometimes different fields, which makes their

conclusions too heterogeneous to extract anything like a common theoretical framework or line of thinking or methodology (cf., Hommel & Wilson, 2002, 2015, 2016). Worse, many counter-reactions put forward valid arguments against their main theoretical target, but the way these arguments relate to the human body or the action it generates often remain rather vague and metaphorical. Given that the approaches vary sometimes dramatically in theoretical aims, scope, and precision, I will not try to systematize the available approaches or to trace each one back to its particular theoretical context. Rather, I will try to extract a number of conceptual questions that seem to drive at least a substantial number of the available approaches. In a first round, I will go through the most salient conceptual themes and critically discuss whether and to what degree they imply a relevant role of the body in human cognition. Then I will suggest a theoretical framework to organize the discussion of these themes and briefly sketch how this organization may work. Finally, I will present a brief to-do list that I think is necessary to work through in order to better understand how human cognition is embodied.

Conceptual Themes of the Embodiment Movement

Representation

While we will see that many members of the embodiment movement deal with some aspect of representation, other approaches are more radical in this respect in denying the need for any representation. Proponents of a radical/nonrepresentational embodied cognitive science (e.g., Chemero, 2009) took inspiration from the ecological psychology of James Gibson (e.g., 1979; Dreyfus, 2002) and the constructivist theorizing on enactivism along the lines of Maturana and Varela (e.g., Clark & Toribio, 1994; Varela et al., 1991; for a comparative discussion and integration, see Baggs & Chemero, 2021; Raab & Araújo, 2019). Some of these approaches have characterized themselves as relying on the idea that cognition is situated, in the sense that cognitive activity and knowledge utilization always take place in a particular context. We will see that not all authors subscribing to this

view deny the relevance of representations (e.g., Barsalou, 2008), but true proponents of radical embodied cognitive science do. The situated-cognition approach was fueled by developments (or the lack thereof: Brooks, 1999; Clark, 1997) in cognitive robotics, where the authors have emphasized that much if not all information needed for behavior does not need to be stored or predicted but can be picked up from the current environment (e.g., Clancey, 1997; Pfeifer & Bongard, 2006). This is considered to be important by reducing the complexity of (Brooks, 1991) and speeding up (Pfeifer & Scheier, 1999) real-world decision-making and behavior, which is seen as a strong advantage over cognitive-robotics approaches that heavily rely on stored information and world models.

Representation-skeptics commonly point out the informational richness of the environment of agents, often in a Gibsonian (Gibson, 1979) sense (e.g., Rietveld & Kiverstein, 2014; Wilson & Golonka, 2013). This reasoning is based on the intuition that the more information the environment provides, the less the perceiver/actor needs to contribute to this information. Once all informational sources in the environment are understood and described, nothing would be left to the perceiver/actor, so that no representations need to be attributed to him or her. Unfortunately, this view confuses the source of information with the way it is used. On the one hand, the richness of environmental information does speak to the question of how much a perceiver/actor can rely on external information and how much internal contribution through stored memories is necessary. It is true that this remains a theoretical consideration, because even if the environment provides all necessary information, it would still need to be demonstrated that the perceiver/actor indeed uses this information, rather than internally stored information. But the general line of the argument is well taken. On the other hand, few non-ecologists/non-enactivists would deny the need and benefit of environmental information for perception and action control, which makes it difficult to see in which sense the key claim of ecological approaches might be "exciting" or "radical" (e.g., Baggs & Chemero, 2021; Wilson & Golonka, 2013), and in which sense it might challenge the concept of representation as it is, often implicitly, used in cognitive psychology and the cognitive neurosciences.

Cognitive psychologists commonly speak of a representation if there is some functional internal state that is correlated with some external state of affairs, and cognitive neuroscientists do the same with respect to neural internal states. Hence, if it is the case that every time a perceiver sees a cherry, or a particular cherry, he/she can be demonstrated to generate some functional or internal state, this state is considered to represent the cherry—irrespective of whether this state is used or perceived by someone or something, and whether this use is considered "mental". From a functional perspective, assuming such representations is useful because it identifies the function of the state as reflecting a relationship between some external state of affairs, the particular perceiver/actor, and some processes that are affected by this relationship. It is also useful by helping to understand how and why a perceiver/actor can carry out internal or external operations with or on the represented state of affairs even in the absence of that state of affairs. For instance, people can simulate picking a cherry from a tree without seeing the tree or the cherry, which would be hard to understand if these people could not somehow reproduce internal states that are similar to the states that a real cherry and tree would produce. Obviously, the same holds for neural states: if perceiving a real cherry and imagining seeing a cherry generate the same or similar neural activity, which we know they do, it is hard to see what would be wrong in calling this activity a representation of the cherry or of seeing the cherry.

These issues are commonly not addressed by radical anti-representationalists, who systematically restrict their examples to tasks that are likely to rely on substantial amounts of environmental information, like grasping an object, but entirely ignore tasks that do not and cannot, like grasping when blindfolded, or writing an article, or singing a song. Anti-representationalists are also reluctant to provide concrete processing models that explain how environmental information eventually moves a muscle to generate the action under discussion. If they would, they would need to explain how the perceiver/actor reconfigures him- or herself in order to pick the cherry, rather than playing soccer, say, and how the environmental information is actually brought into contact with, and how it controls the activation of the muscle driving the action. In other words, anti-

representationalists choose to not touch theoretically what happens between people's ears, making it feasible to do without representations.

However, the main target of the theoretical criticism does not seem to be representations in the trivial sense that I have discussed so far. Rather, anti-representationalist papers often construe some kind of contradiction between the concept of "mental representations" on the one hand and the idea of "perceptually guided motions through the world" on the other (Wilson & Golonka, 2013). And yet, while one can argue about the usefulness of the widespread custom to qualify representations as "mental", it is hard to see why the representation concept as such should be incompatible with attempts to account for perceptually guided action. Generating perceptually guided action requires environmental information to get in touch with muscles moving the respective limbs, which in turn requires the channeling of perceptually extracted information from the sensory surface through to action control. In this way, the information needs to be coded and frequently recoded, which means that the external information needs to be internally represented—and it is this trivial necessity that most cognitive psychologists and neuroscientists have in mind when speaking about representations (e.g., Raab & Araújo, 2019). This is even more obvious if the environmental information is no longer available, such as if one closes one's eyes before starting to reach for an object: how could one ever achieve this if one were not able to represent the previously available information off-line? The ability to re-present or recode external information does not necessarily suggest any high cognitive work, consciousness, or understanding; it simply refers to the obvious fact that information needs to be transported through the central nervous system to do its job. Apparently, this concept of representation is much more trivial than what anti-representationalists argue against. Anti-representationalists also seem to believe that assuming the existence of representations implies that cognitive content and cognitive processes are disembodied (e.g., Chemero, 2009; Wilson & Golonka, 2013; for a broader discussion see Dove, 2011). However, it is hard to see how assuming that external states of affairs are systematically correlated with internal states of affairs, as cognitive psychologists and cognitive neuroscientists do,

necessitates the assumption that cognitive processes have nothing to do with the body. Indeed, we will later see that a number of theorists that subscribe to the embodiment movement are explicitly discussing that and how representations bring the body into play—which seems to undermine the basic assumption that representations and embodiment are incompatible concepts.

To summarize, the representations that anti-representationalists are against seem to be different kinds of representations than those assumed to exist by modern cognitive psychologists and cognitive neuroscientists, so that the actual target of the criticism remains to be identified. For mainstream cognitive psychology/neuroscience, the assumption of representations in a trivial sense (i.e., internal states that systematically correlate with external states of affairs) does not seem to rule out the possibility that human cognition is embodied, and does not even seem to be related to the question of whether and how the embodiment of human cognition works. Worse, the systematic reluctance of anti-representationalists to develop concrete mechanistic models that explain how the environmental information they are interested in actually drives the movements that they emphasize stands in the way of further theoretical developments that would help us to understand how and in which sense human cognition is embodied.

Cognition

Some authors are less interested in issues related to representation in general, but focus on the role of cognition in decision-making and action control. Again, some of the pioneering authors were motivated by their disappointment about progress in cognitive robotics (e.g., Brooks, 1999; Clark, 1997), while others relied on research on human thinking (e.g., Gigerenzer et al., 1999). The key intuition is that cognitive processes are slow and often too comprehensive, or more comprehensive than necessary, which implies that truly effective decision-making and action control should not rely on cognitive processes at all, or at least not in time-critical situations. This obviously raises the question of what the alternative might be, and here the answers are rather different. While some authors have

brought overlearned habits, generic biases, or spontaneous heuristics into play (like Gigerenzer et al., 1999), others have considered sensorimotor processes (e.g., Körner et al., 2015)—which implies a closer connection to the embodied-cognition idea. The main conceptual problem in these approaches is that they fail to define the concept of cognition, which makes it difficult to judge whether this concept is truly independent of the alternatives it is put into opposition with.

The term goes back to Greek for "I know, perceive" and, according to a typical definition, refers to "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses" (http://www.oxforddictionaries.com, retrieved 1.2.2020). This implies a very active role of the person who is busy with knowledge acquisition and understanding, and the definition seems to be relatively "disembodied"—if one neglects the fact that the senses belong to, and are carried by a body that also mediates the experience. Engaging in cognitive processing is also often explicitly or implicitly associated with conscious representation, as, for instance, implied by the work of Gigerenzer et al. (1999), Kahneman (2011), or Dijksterhuis and Nordgren (2006). Given that the buildup of conscious states is notoriously slow and sensitive to biases (Hommel, 2013; Kahneman, 2011), it makes a lot of sense to assume that relying on such states slows down information processing to a degree that stands in the way of fast and efficient decision making and action control.

However, since the cognitive revolution in the 1960s and 70s, when Neisser (1967) defined cognitive psychology as "the study of the mental processes involved in acquiring knowledge"—a definition that is still very close to the Greek roots of the term cognition, the semantics have slowly but consistently liberated the term from such roots. Both cognitive psychology and the cognitive neurosciences are interested in the processes ***underlying*** cognition, without the requirement that each process shares all the characteristics that the emerging property the process contributes to is assumed to have. Hence, there is no reason to assume that the processes generating cognition are as conscious and as slow as the cognitive act that they are assumed to contribute to. Unfortunately, cognitive psychology and the cognitive neurosciences tend to label the processes underlying

psychological phenomena according to these phenomena, which is why theorists speak of memory processes, attentional processes, perceptual processes and, indeed, cognitive processes. As I have elaborated elsewhere (Hommel, 2019a, in press), this is unfortunate for two reasons: it blurs the line between the explanandum (such as cognition) and the explanans (the interaction of processes explaining the emergence of cognition), and it falsely suggests that the respective processes are dedicated and reserved for the psychological functions the label of which they carry (e.g., implying that a "memory process" cannot also be an "attentional process"). Importantly, if we correct for these terminological inaccuracies by translating "cognitive processes" into "processes that contribute to the emergence of human cognition", there is no reason to believe that all processes contributing to cognition are necessarily slow or too comprehensive. There is also no reason to believe that the processes underlying human cognition, defined in whatever way, show zero overlap with the processes that one assumes underlie the conceptual alternative, be it a habit or a sensorimotor process.

Taken altogether, anti-cognitivist critics may well be right in assuming that efficient decision-making and action control does not rely on conscious representations. However, given that few, if any mechanistic models of decision-making and action control suggest such reliance, it remains unclear against which approaches such critics are arguing. It is possible that much of the respective controversy rests on a misunderstanding of the term cognition, and in particular on its inaccurate application to the processes that are assumed to generate human cognition. The key question that remains is whether, and to what degree, these processes relate to the human body and the activities it unfolds. But even if they strongly rely on the body and its activities, there would be no contradiction in assuming that they also underlie human cognition—which is indeed what the term embodied cognition implies. Hence, anti-cognitivism does not seem to be a logical theoretical motive to favor the idea that human cognition is embodied.

Format

Some authors of the embodiment movement are less skeptical with respect to the general idea of representations but more interested in the format of representations. In contrast to the symbolic view suggested by GOFAI, embodiment theorists tend to assume that cognitive representations are distributed and modal, that is, still capturing aspects of the sensory or sensorimotor activity that served to pick up the respective information. The authors differ with respect to the degree to which they allow for symbolic, abstract, and amodal representations in addition to less abstract or modal representations, and the degree to which action-related information is considered to be part of modal representations, but the unifying assumption is that abstract symbols cannot be all there is (for an overview, see Barsalou, 1999, 2008).

Even though many embodiment theorists assume some degree of modal representation, not all proponents of modal representations are necessarily embodiment theorists. (This depends on their definition of "modal", on which there is no consensus: Haimovici, 2018.) Modal representation has also been put forward as a means to provide a better grounding of internal representations. For instance, the assumption of abstract symbols has raised the question of where symbols are coming from in the first place and exactly how they actually acquire their meaning (Harnad, 1990). To really understand what the term red means arguably requires some exposure to something red, which brings in perceptual experience, and representations reflecting that experience, as an important mediator of symbol grounding. If representations carry concrete aspects of their acquisition history, the grounding problem could be reduced and eventually be solved (Barsalou, 1999). While this theoretical move might include information about the body and action, this information may not always be a necessary ingredient, which implies that not all evidence supporting modal representation necessarily requires the assumption that cognition is embodied (Barsalou, 2008).

Given that embodiment theorists agree in rejecting radical symbols-only approaches, it is not surprising that all embodiment approaches that include specific assumptions regarding representations have opted for what one may call compositional representations—integrated bindings of codes that represent

information about the sensory features of the represented event, perhaps in addition to action-related features and other information. The exact nature and the format of these codes are not yet clear, however. Some authors assume that these codes represent the sensory modality used to extract the respective feature (Barsalou, 1999), and there is quite some evidence that relating information that was extracted by the same sensory modality is easier than relating information extracted by different modalities. However, if modality-speciﬕc codes would be all there is, one would need to explain how the same information in two or more sensory modalities (like the smoothness of an object extracted by vision and touch) is related to each other, and how perception can inform action control. As pointed out by Prinz (1992), effective communication between perception and action requires some kind of common currency or common coding that both can relate to, which is not provided by codes representing modality-speciﬕc perceptual and action-related state of affairs (e.g., the way visual neurons are coding for a round object has no resemblance to the way muscles are controlled to reach for a round object). Communication between perception and action requires a distal reference (Heider, 1926/1959: i.e., information about the external object and the external interaction with it) rather than a proximal reference (as provided by modal codes). This does not rule out the possibility that some representations of external events are modal, but other representations need to be as amodal as their distal reference requires—in addition to being compositional (Hommel, 2009; Hommel et al., 2001a).

Taken altogether, there is widespread agreement that the representations that embodied cognition relies on the need to be compositional in one way or another. Minimally, representations need to represent perceptual characteristics of the represented events, possibly in addition to codes representing the action related to that event. These representations may include modal information, but some more amodal (but still feature-based) codes are important to understand inter-modal integration and communication between perception and action.

Simulation

Various authors of the embodiment movement have suggested that both perception (Barsalou, 1999) and action planning (Gallese & Goldman, 1998) are not only associated with, but even require, some sort of internal simulation to operate properly. Simulation theorists see evidence for their claims in studies that for instance show that people respond faster to pictured objects if the shape of these objects is implied by a sentence that they read before (Zwaan et al., 2002). Along the same lines, planning an action has been observed to activate brain areas that are similar to those that are activated when merely imagining performing the action (Gallese & Goldman, 1998). What remains unclear in simulation views is what purpose the simulation may have. What would it be good for to generate visual images of objects described in a sentence when reading it? Some authors escape this question by arguing that simulation is automatic (e.g., Körner et al., 2015), which seems to render the possible functionality irrelevant. Others have explicitly asked the functionality question and either could not identify a particular purpose (e.g., Bergen, 2015) or explicitly considered simulation epiphenomenal (Mahon & Caramazza, 2008).

A key problem of the simulation view is causality. In order to demonstrate that simulation is a necessary requirement for meaningful perception and action planning, it would be necessary to show that preventing simulation makes perception and action planning impossible. While there are a few studies showing that introducing secondary tasks or interfering events that are assumed to hamper simulation (or the processes assumed to rely on simulation) signiﬁcantly impairs performance (e.g., Grade et al., 2015; Witt & Proffitt, 2008), ﬁnding delays of a couple of milliseconds or a slight drop of accuracy is a far cry from showing that perception and action planning no longer work without simulation. Another problem is that it remains unclear what the term simulation actually implies. For instance, Bergen (2015) traces the concept back to Wernicke (1874/1977, p. 117), who claimed that the concept of the word “bell… is formed by the associated memory images of visual, tactile and auditory perceptions”. Note that this assumption does not go anywhere beyond the claim that objects are represented by codes that

relate to feature information provided by different modalities, as discussed above. Wernicke's idea may thus simply come down to the assumption that representations are composites of feature codes, so that facing an object is likely to reactivate codes that represent different kinds of features of this object. Calling this a simulation may or may not be semantically meaningful but it seems to create quite a bit of unnecessary interpretational overhead, such as implying someone or something that is doing the simulation and someone or something for which it is done. Someone is indeed implied by considering simulation a "reenactment of previous experiences" (Pecher & Winkielman, 2013, p. 396)—which seems to imply a person having had an experience and now having it again.

To summarize, claims that perception and action planning involve internal simulation are still in need of convincing evidence that simulation is an integral part of these processes, and even if such evidence could be provided, it remains unclear in which sense simulation renders cognition embodied (especially if one considers that even simulations ***about*** the body do not actually involve it). Very likely, a feasible definition of simulation will turn out to be going not much beyond the assumption that perception and action planning involve the reactivation of feature codes that represent earlier-acquired, modality-specific object or event information.

Bodily States

Some authors of the embodiment movement have focused on the role of bodily states in human cognition. For instance, Körner et al. (2015) have argued that the potency of sensations and actions to "directly alter a person's state of mind, feelings, or information processing" represents a mechanism underlying embodied cognition. Empirical examples assumed to indicate such a potency derive from various attempts to prime all sorts of internal states, often by means of task-unrelated stimuli (for an overview, see Janiszewski & Wyer, 2014). Many of these demonstrations have been challenged just recently, and they seem to be difficult or impossible to systematically replicate (e.g., Chivers, 2019). More interesting for present purposes are the

theoretical implications of these approaches, however, and in particular their relevance for embodied cognition.

For many of the findings of priming studies, a connection to embodied cognition is anything but obvious. For instance, the ability of attended or unattended, conscious or unconscious stimuli to trigger a particular behavior seems unrelated to the question of whether and in which sense cognition is embodied, and the same holds for stimuli that may activate a particular goal or motivational orientation. Depending on the theoretical background, these kinds of priming effects might even be consistent with a GOFAI-compatible view that is based on symbol manipulation. Similarly, observations of what one may call metaphorical associations, like when being exposed to physical warmth promote interpersonal warmth (e.g., Williams & Bargh, 2008; but see Lynott et al., 2014), are likely to require the assumption of compositional, feature-based representation (so that one representation can prime another based on feature-overlap) but have no obvious bearing on any involvement of the human body. More relevant seem to be priming effects caused by experimental manipulations of bodily states, such as demonstrations showing that assuming a particular posture systematically or activating muscles that are involved in smiling affects the affective judgment of objects (see Laird, 2007; Neumann et al., 2003). On the one hand, these kinds of demonstrations provide clear-cut evidence that bodily states can have an impact on human cognition. On the other hand, however, there are several reasons why they do not speak to the question of whether cognition is embodied.

First, demonstrating that changing bodily states ***can*** affect cognition does not necessarily imply that bodily states are involved in and represent a necessary ingredient in ***all*** kinds of cognition. Second, because bodily states need to be ***perceived*** in order to impact cognition; so that it eventually is perceptual information has the impact, and the notion that cognition is affected by perceptual information does not seem to be a unique theoretical assumption. For instance, there is evidence that people differ substantially with respect to their interoceptive abilities (Schachter, 1971), suggesting that some people's cognitive processing is affected more strongly by interoceptive information than others. This implies that cognitive

processing is affected by information provided by multiple sensory modalities, as many authors assume (see above), with interoception representing just one of many informational sources. Accordingly, there is no reason to assume that interoceptive informational sources have a privileged access to perception and action control, which in turn suggests that the bodily states that interoception informs about do not play a particularly dominant role in human cognition. Third, even the most hard-nosed symbolic approach is unlikely to deny that people sense and represent interoceptive information and that this information may become associated with, and be taken to represent, particular internal states. If so, it is hard to see why the demonstration that bodily states can impact cognition might require a particular kind of non-symbolic representation, as the embodied cognition movement claims.

To summarize, the available evidence suggests that interoceptive information has an impact on perception, decision-making, and action control. However, it is hard to see why these observations require the assumption that the sources of this information have a particularly dominant or theoretically noteworthy role in human cognition.

Action

Some authors of the embodiment movement have emphasized the role of action in representing external objects and events. The way and the degree to which action is considered to contribute to cognition differ substantially, however. Some have emphasized that the purpose of human cognition does not consist in amassing information about the world but, rather, in informing action control (e.g., O'Regan & Noe, 2001), even though it is not always clear how this basically evolutionary insight guides further theorizing. For instance, Milner and Goodale (1995; authors that might not consider themselves as part of the embodiment movement but that are sometimes cited in this context: e.g., Wilson, 2002) have argued for a dual-pathway model, according to which at least visual information is channeled through to a slow, central system that integrates the information with already available world knowledge, and to a fast system that feeds more or less uninterpreted information into ongoing motor control. This model is

consistent with claims of those authors of the embodiment movement that have argued for a direct, not cognitively mediated impact of sensory information on action control (e.g., Körner et al., 2015). Others have taken the cognition-for-action principle to imply that representations are sensorimotor in nature and mainly created for action control, rather than for a valid internal reconstruction of the environment (O'Regan & Noe, 2001). Note that these two examples differ substantially in that the assumption that cognition is for action is taken to imply a particular neural architecture in the first case and to imply a particular format of cognitive representations in the second. These two perspectives need not be incompatible, but they are very different in nature and regarding further theoretical and empirical implications. Even other authors have linked the cognition-for-action perspective to the assumption of internal simulation. For instance, Gallese and Goldman (1998) argue that perceiving events leads to the internal simulation of their motor implications, and that this forms the basis for the ability to imitate and to understand the actions and intentions of others. Again, this perspective is entirely unrelated to the dual-route idea of Milner and Goodale (1995) and the sensorimotor-representation claim of O'Regan and Noe (2001).

Critical discussions of cognition-for-action approaches are just as incoherent as the available approaches themselves. For instance, Wilson (2002) questions these approaches because, as she argues, there is evidence that representations may contain more information than strictly necessary for a particular action, that they may contain non-physical information, and that a non-direct system exists in the Milner and Goodale approach. Not only is this criticism missing the point of other authors, like O'Regan and Noe (2001) or Gallese and Goldman (1998), but it also dismisses the possibility that even the most direct information processing can leave traces behind that can be used for other purposes than the control of the ongoing action. To engage in a more fruitful discussion requires the distinction between at least three different issues that different cognition-for-action approaches have put forward.

First, if cognition is for action, one might expect a particular functional ***architecture*** of the cognitive system. For instance, Allport (1987) has taken the cognition-for-action principle to argue against

information-processing models that have interpreted performance limitations of informational transfer to processing bottlenecks, as evident in the attribution of selective processing to attentional overload. Considering that information is processed for the purpose of action control brings other interpretations into play, such as the fact that each effector can be involved in only one action at one time. The architecture suggested by Milner and Goodale (1995) is also derived from functional considerations that try to account for the human ability of both slow off-line reasoning and fast online acting.

Second, if cognition is for action, one would expect a closer linkage between representations of, or plans for action and representations of objects and other action-relevant information than standard information-processing stage models imply. This is an argument that relates to the ***format*** of cognitive or cognitively relevant representations and that is also consistent with many of the already mentioned approaches suggesting that representations are multimodal, distributed, and/or composites of feature codes that include action-related information.

Third, cognition for action might provide the basis for ***using*** functional or neural representations used for action control for cognitive purposes. Whether the activation of motor structures is sufficient to subserve these purposes, as suggested by Gallese and Goldman (1998) and other simulation theorists, remains to be seen. For one, there is very little evidence that can be taken to provide unequivocal support for the claim that cognitive functions like understanding other people is impossible without motor simulation (see Galetzka, 2017). For another, there is no mechanistic model that would explain why mimicking the motor states of other individuals translates into understanding them better. Finally, there is no mechanistic model explaining how motor states can be perceived by the individual having them. One might argue that activating motor states leads to the activation of the expected reafferent outcomes of the actions these states are able to drive, and it may be the representations of these outcomes that provide the perceiver/actor with the information necessary for understanding others. But this would imply that it is actually the representations of the expected outcomes that are doing the trick, while activated motor states may be

just one of the perhaps many ways to activate these representations. Whatever the eventual conclusion, using action-related representation for cognitive purposes does not necessarily imply a particular format of these representations or a particular neural architecture of information processing, which renders these three applications of the cognition-for-action principle relatively unrelated.

Towards a Mechanistic Theory of Embodied Cognition

What I tried to show is that the embodied cognition movement is indeed very incoherent and driven by many different, sometimes unrelated issues and theoretical lines of reasoning. This remains a real problem that stands in the way of a smooth development of the underlying ideas. At the same time, however, the different approaches that are part of the movement do show some family resemblance in the sense of Wittgenstein (1953/2001), and they more or less agree on the rejection of exclusively symbolic representation, a preference for compositional, distributed representations, and at least some reliance on action. Hence, even though the widespread lack of agreement with respect to details might be disappointing and discouraging, there is too much overlap and agreement to take the current incoherence as a reason to dismiss the entire movement. However, what is strongly needed is more mechanistic theorizing. It is a mechanistic theory that helps operationalizing the often airy and metaphorical theoretical claims of embodied cognition approaches and translating them into concrete, causal mechanisms and well-defined representations on which these mechanisms operate. Elsewhere (Hommel, 2015, 2016) I have argued that the first step towards a mechanistic embodied-cognition account might borrow from the Theory of Event Coding (TEC: Hommel et al., 2001a), which not only addresses the main conceptual themes that are motivating embodiment approaches, but that also addresses them in a way that is compatible with many of them. Given that it is a theory that considers the concept of representations (in the above-explained trivial sense) useful, using TEC to operationalize embodied cognition will not satisfy radical anti-representationalists, but even for theorists from this camp TEC may

represent a concrete and motivating challenge for improving the mechanistic aspects of their own theorizing. For others, TEC provides a basic framework and a conceptual toolbox that I believe can help to organize discussions about more specific mechanisms and representations, which eventually may lead to a truly mechanistic embodiment theory. It is important to emphasize that TEC is not a specific theory about a specific phenomenon, but rather a meta-theoretical framework that helps to organize the construction of more specific, mechanistic, and empirically testable models and, most importantly, of alternative models that can be directly pitted against each other.

TEC was developed to account for various empirical phenomena suggesting a much closer link between perception and action than previous stage models would allow for, such as stimulus–response compatibility, response-stimulus compatibility, interactions between action planning and attention, and action imitation. It was motivated by ideomotor theorizing (for a review, see Shin et al., 2010), with which it shares the idea that people continuously pick up and store contingencies between their movements and the sensory, re-afferent effects that these movements generate—similar to the approach of O'Regan and Noe (2001). The binding between the motor pattern driving the movements and the codes of the effect of the movement is called an event file (Hommel, 2004), and sensorimotor event files are considered to be the core unit of the cognitive system. More specifically, TEC makes four basic assumptions (Hommel et al., 2001a; Hommel, 2015): (1) perceptual events and planned actions are cognitively represented by event codes; (2) event codes are integrated assemblies of feature codes (event files); (3) which can be taken to represent cognitive or brain states that correlate with perceived or self-generated features; (4) so that the basic units of perception and action can be considered sensorimotor entities that are activated by sensory input—a process commonly called perception—and controlling motor output—a process commonly called action. Hence, according to TEC, "perception" and "action" are not just related, associated, or intertwined but, rather, two terms that refer to the exact same thing: while perception consists in the process of actively generating input that informs about environmental states of affairs

and their relation to one's own body, the action consists in the process of actively generating environmental states of affairs that the agent is intending. That is, both perception and action consist of moving to generate particular input, only that the term perception is used to emphasize the input-generating function while the term action is used to refer to the intention-realization function.

How does TEC relate to the conceptual themes favored by embodied-cognition theorists? This is not the place for an overly detailed assessment of this issue, the more so as I have already elaborated elsewhere how TEC relates to various aspects of embodied cognition (Hommel, 2015, 2016). I will also not go into mechanistic details but refer the interested reader to computational implementations of TEC (Haazebroek et al., 2017; Kachergis et al., 2014) and to a number of recent extensions of TEC to cover cognitive control processes and representations of self and social events (Hommel, 2018, 2019b). I will instead restrict myself to a brief sketch explaining how and in which sense TEC can be taken to address the conceptual themes that the embodiment movement is interested in (see Table 26.1 for a brief summary of the respective concept, the most extreme arguments, possible solutions, and corresponding TEC mechanisms). As already mentioned, TEC claims that perception and action control are based on feature codes and event files, which are intermodal, sensorimotor representations. This will not address any radical anti-representationalist criticism, but is consistent with the large majority of the more representation-friendly embodied cognition approaches. At the same time, TEC is not sensitive to any criticism of cognition-skeptic theorists. For one, TEC is agnostic with respect to the possible contribution of conscious awareness. There is strong evidence that event files can be activated in a very short time, irrespective of whether the activation is or is not task-relevant (Kühn et al., 2011), which rules out arguments that "cognitive" representations are too slow to make meaningful contributions to effective action, at least with respect to the representations that TEC considers relevant. The representations of TEC are also not disembodied, because the representation of each object or event is assumed to contain information about the action that was carried out to sense or generate the object or event, or to interact with it. Hence,

object or event representations are shaped by, and reflect the action it relates to and the agent carrying it out.

Table 26.1 Embodiment concepts, arguments, possible solutions, and corresponding TEC mechanisms.

Concept	Purist claim	Rich claim	Possible solution	TEC mechanism
Representations	Do not exist	Explain cognition	Functional interpretation: mere correlates of environmental information	Event files: bindings of feature-specific (amodal) codes
Cognition	Too slow to intervene, bypassed	Intervenes between and controls perception and action	Treat cognition as explanandum, not explanans; focus on processes underlying it	Generated/expressed through sensorimotor interaction
Format	Modal, distributed	Symbolic	Consider feature-based, hierarchical coding with modal codes as basis	Feature-specific (amodal) codes
Simulation	All action relies on	Artifact or byproduct	Treat as (not strictly necessary) option, identify contingencies	Activation of to-be-expected sensory action effects
Bodily states	Mediate access to body, action	Coded in abstract form	Treat as one code among many	Coded as any other modal information
Action	Purpose of perception, cognition	Causally irrelevant consequence of cognition	Consider perception and action as two sides of same coin	Emphasizes the generative (rather than receptive) aspect of sensorimotor activity

TEC assumes that event files represent distal information (Hommel, 2009; Hommel et al., 2001a), which means that the codes these files contain reflect characteristics of the event they represent but not the characteristics of the modality that provides information about the event. As Prinz (1992) has pointed out, it is this distal reference that provides the common code for relating perception and action and allows perception and action to talk to each other. This implies that feature codes are amodal, which seems to be inconsistent with claims of embodiment and grounding theorists like Barsalou

(1999). However, as explained above, I believe that this inconsistency is only apparent. For one, the main goal of modal theorists—the construction of sub-symbolic representations that keep some of the flavor of the sensory or sensorimotor activity used to acquire the represented information—is still achieved. And, for another, modal and amodal information about sensory and action features may simply represent different kinds or integrative levels of a more complex representational scheme (Haazebroek et al., 2017).

Given the sensorimotor nature of TECs core units of the cognitive system, being exposed to an object or event is not unlikely to activate motor patterns. Whether that actually happens depends on the context, and in particular on what TEC calls intentional weighting (Memelink & Hommel, 2013). According to TEC, features are organized into feature maps and the contribution of activations from a particular feature map are weighted according to the (actual or assumed) task-relevance or contextual salience of the respective feature dimension. The weighting of feature contributions implies that not all ingredients of a given event file contribute equally to action control, and that the contribution of each feature and feature dimension can vary over time in context. This also implies that the degree to which facing an object or event spreads activation to motor information contained in the event file can vary. This means that TEC shares the assumption of the more action-related simulation theories that perceiving an event can lead to corresponding motor activity (e.g., an object may activate a grasping movement it "affords"; see Tucker & Ellis, 1998), but it does not share the assumption of some theorists that priming motor activity is obligatory or necessary to penetrate the meaning of the event (cf., Galetzka, 2017). Moreover, TEC provides the theoretical guidance needed to systematically vary the amount and degree of motor activation through appropriate instruction and task settings. Finally, TEC logic suggests that "event-file activation" might be a more appropriate and less homunculoid theoretical term than "simulation".

TEC allows for codes of features derived from interoception to be integrated into event files but does not consider these codes particularly dominant or relevant for action control. TEC does emphasize the role of action in human cognition, and actually considers action to be the key tool to generate knowledge about

environmental conditions, about oneself (Verschoor & Hommel, 2017), and about the goals one might consider achieving in the future (Verschoor et al., 2010). With respect to architecture, TEC is consistent with Milner and Goodale's (1995) distinction between a fast and direct sensorimotor route and a more cognitive route, but it would suggest a change in conceptualization and terminology. In particular, TEC suggests that setting up and planning goal-directed action calls upon what Milner and Goodale have termed the perception route, which thus seems to be a misnomer from a TEC perspective. Rather, TEC can be seen as an implementation of Milner and Goodale's cognitive route, which creates and establishes action plans that are then driven by Milner and Goodale's direct route (Hommel et al., 2001b).

Taken altogether, TEC seems to provide a sufficiently rich conceptual toolbox to speak about the main conceptual themes discussed by the embodiment movement. This toolbox makes it possible to construct otherwise comparable alternative models that can be tested against each other, which is likely to advance our insight into how cognition is embodied and how embodied cognition actually works. Hence, TEC is likely to better organize the work to be done, but it does not take away the efforts needed to meet the challenges ahead, to which I will now turn.

Challenges Ahead

A relatively fundamental challenge with strong theoretical implications has to do with the relationship between radical anti-representationalists and the majority of embodiment theorists that are less afraid of the concept of representations. Theorists relying on representations need to become more specific with respect to how they understand this concept. I have suggested that using the concept to refer to the obvious fact that information needs to be transmitted from the environment, through the receptors, to motor systems, and back is unlikely to cause any theoretical harm and is unlikely to provide the basis for an interesting theoretical discussion. Once anti-representationalists begin going beyond very high-level, descriptive models that try to capture the dynamics of some aspect of human action and dig deeper into causal mechanisms that generate this

behavior, they will need to develop some concept that explains how the environmental information gets from A to B, and it is not hard to predict that this concept will look very similar to the trivial use of the representation concept. However, some representationalist theorists seem indeed to entertain richer interpretations of the representation concept that seem to include some degree of understanding or other "mental work". It seems to be this use of the concept that represents the real target of anti-representationalists. Encountering this part of the criticism requires the respective representationalist theorists to provide mechanistic models that operationalize this richer representational concept. Truly mechanistic models require a detailed specification of the structure and origin of representations, and of the processes operating on them (Hommel, 2020), and this degree of specificity is commonly missing especially in the cognitively richer and/or more metaphorical embodiment approaches.

A related challenge consists in the development of mechanistic explanations of where representations are coming from. One of the major criticisms of the assumption that human cognition relies on symbol manipulation was that this assumption raises the grounding problem, that is, the question of where the symbols are coming from. Embodiment theorists agree that allowing for compositional representations helps reduce this problem, but really eliminating it requires a better understanding of the acquisition process. This will call for more developmental and experimental proof-of-principle studies demonstrating the acquisition of representations of new, unfamiliar events. The neuroscientific monitoring of the acquisition process would also provide interesting converging evidence.

Another challenge relates to the role of modal information. As explained above, if all compositional information would be modal, we would need to explain how the intermodal integration of feature codes works and how perception can effectively communicate with action control. This suggests the existence and important role of compositional, feature-based information that is amodal in nature. Do modal and amodal codes coexist? How do they relate to each other and how are they acquired? More systematic experimental strategies need to be developed to investigate this issue and, again, neuroscientific methods may provide interesting converging evidence.

Yet another challenge relates to the role of action. One possibility is that action represents the essential ingredient of the representation-acquisition process, as, for instance, suggested by ideomotor theories and TEC: by actively exploring his or her environment, the perceiver/actor integrates motor codes of the movements with their sensory consequences. Once this integration is completed, the integrated representation can be used both online, as in mimicry or imitation, and off-line, as, for instance, in action planning. However, this perspective would not necessarily require the action-related ingredients of the representation to be active all the time, irrespective of the current task and purpose. Simulation accounts would in contrast maintain that activating these ingredients is obligatory and difficult or impossible to prevent, and perhaps even necessary to really understand the perceived event. In other words, there is a range of possibilities regarding the role action-related codes can play off-line and online, and more systematic empirical strategies are necessary to identify the most plausible ones. This requires going beyond proof-of-principle demonstrations and calls for more systematic, theory-guided experiments digging into concrete mechanisms and their contextual and individual variability.

A related question is whether there is a strong need for the concept of simulation. It does carry quite some homunculoid baggage by implying someone who carries out the simulation and someone for which it is carried out. Alternatively, it is possible that the available evidence is sufficiently well explained by assuming that, due to the compositional nature of representations, being exposed to a perceptual event may, depending on task and circumstances, activate action-related ingredients of the representation. If this is all there is, there need not be any particular purpose of this activation. It simply reflects the compositional nature of the representation. Calling it activation or priming, rather than simulation, seems more appropriate in this case, which would help to avoid theoretical overhead and anti-cognitivist suspicions. It also seems important for simulation theorists to develop a more mechanistic idea about what is meant by “meaning” and “understanding”, and whether these concepts go anywhere beyond mere activation of representations.

To conclude, to reach the next level of understanding where, whether, and how human cognition is embodied, more systematic and more mechanistic theorizing is necessary, as is more theory-guided experimenting with the aim to become more specific with respect to the representations underlying embodied cognition and the processes operating on them. TEC may provide a useful framework to organize these endeavors, but substantial theoretical and empirical efforts will still be required.

Acknowledgements

This research was supported by an Advanced Grant of the European Research Council (ERC-2015-AdG-694722) to the author.

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© Springer Nature Switzerland AG 2021
M. D. Robinson, L. E. Thomas (eds.), ***Handbook of Embodied Psychology***
https://doi.org/10.1007/978-3-030-78471-3_27

27. Embodiment in the Lab: Theory, Measurement, and Reproducibility

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Abstract
Embodied approaches to cognition claim that cognitive processes are grounded in systems of perception and action planning. A series of straightforward predictions would appear to emerge from this claim. For example, the understanding of language is posited to rely on internal motoric simulations of actions that have been described, and so the processing of action language should elicit activity in the motor system that can be detected through both behavioral and brain measures. Despite the seemingly straightforward predictions of embodiment, the main claims of embodiment have turned out to be difficult to test in an incisive manner, and the findings generated from these tests have turned out to be fickle in many cases. We discuss the theoretical and methodological issues surrounding embodied cognition, and in doing so grapple with issues about theory testing and the reproducibility of research findings.

Keywords Embodiment – Language processing – Simulation – Replication – Methodology

Embodiment in psychology is the idea that our bodies' systems of perception, action planning, and emotion regulation ground our

abilities to engage in a range of behaviors and mental processes. Simple examples of embodiment include demonstrations that the comprehension of verbs about action (e.g., ***kick***) is grounded in the activity of the motor cortex (e.g., Hauk et al., 2004), that the comprehension of language about action affects the execution of motor responses (e.g., Glenberg & Kaschak, 2002), and that the perception of physical warmth grounds our understanding of the closeness of relationships (e.g., Fay & Maner, 2012; Williams & Bargh, 2008). Elements of an embodied approach to psychology have deep roots in the field (see Proctor & Chong, this volume), but the notion of ***embodiment*** writ large has only gained a degree of prominence in the field within the past two decades. From its beginnings in linguistics (e.g., Gibbs, 1994; Lakoff & Johnson, 1980), philosophy (e.g., Harnad, 1990), and robotics (e.g., Brooks, 1991), embodiment has spread throughout psychology. There are now substantive embodiment-oriented programs of research in different branches of cognitive science, developmental psychology, social and personality psychology, and neuroscience (see the various chapters in this volume to explore embodiment in a diverse range of fields).

Embodied approaches to psychology have garnered an increasingly prominent place in the field, but they have not been without their critics (e.g., Mahon & Caramazza, 2008; Mahon & Hickok, 2016). Some of the criticism has been directed at the theoretical adequacy of embodiment (e.g., Goldinger et al., 2016; Mahon & Caramazza, 2008). For example, Mahon and Caramazza's (2008) discussion of the neuropsychological evidence suggests that concepts and knowledge are largely represented in an abstract format, with sensorimotor representations (i.e., "embodied" representations) playing a limited, specific role in cognition. That is, embodiment is a secondary element of cognition, rather than the grounded basis for cognition (but see Glenberg, 2015, for a counterpoint). Further, Goldinger et al. (2016) argue that embodied approaches cannot provide an account for many of the benchmark phenomena in cognitive science (e.g., word frequency effects). Other criticisms of embodiment have focused on the robustness of the empirical literature (e.g., Papesh, 2015; Rommers et al., 2013). Recent work has shown that the Action-sentence Compatibility Effect (ACE; Glenberg & Kaschak, 2002), an effect widely

cited as evidence for the role of the motor system in the comprehension of sentences about action, cannot be reliably demonstrated in the lab (Morey et al., under review; Papesh, 2015). The reliability of social embodiment effects has likewise been questioned (e.g., the social warmth hypothesis; Chabris et al., 2019). As with much of psychology over the past several years, embodiment-oriented researchers have had to grapple with the ***reproducibility crisis*** that has arisen in the field (e.g., Ioannidis, 2005; Lindsay, 2015; Open Science Collaboration, 2015).

The term ***reproducibility crisis*** refers to a set of related concerns about the validity of the experimental results that are reported in the literature. The concerns include (but are not limited to) questions about appropriate methods of statistical analysis and statistical decision-making (e.g., Benjamin et al., 2018; Lakens et al., 2018), questions about the quality of psychological theories (e.g., Klein, 2014), and questions about whether the results of previously published experiments can be reproduced in other labs (e.g., Open Science Collaboration, 2015). The causes, consequences, and implications of the reproducibility crisis have been discussed at length in other places (e.g., Allison et al., 2018, and other articles from the Arthur M. Sackler Colloquium on Improving the Reproducibility of Scientific Research published in the ***Proceeding of the National Academy of Sciences*** in the March 13, 2018, issue), and it is not our intent to rehash these points here. Rather, it is our intent to use the reproducibility crisis as a lens through which to assess the current state of the embodiment literature, and the research paradigms that are popularly used in the field. Note that although the reproducibility crisis is relevant to all strands of embodied psychology research, our discussion will mainly focus on the literature on embodied approaches to language.

The structure of our chapter is as follows. We begin by briefly discussing a few specific cases where issues of reproducibility have made contact with the embodiment literature. Then, we consider the role that different factors might play in driving replication issues in this field. One set of factors concerns the nature of embodied theories of language comprehension. Another set of factors concerns issues related to the measurement of behavior, and the implications of these

measurement issues for embodiment. We conclude with some thoughts on the future of embodiment research.

Reproducibility and Embodied Approaches to Language Comprehension

Although questions about the reliability of research findings have been raised for many years (e.g., Ioannidis, 2005), the reproducibility crisis became salient in the field of psychology around the year 2011. A convergence of events, such as Simmons et al. (2011) demonstration of the power of researcher degrees of freedom in shaping the outcome of studies, and Bem's (2011) publication of a series of studies purported to show support for the existence of ESP, raised concerns about the reproducibility of research in psychology (see Pashler & Wagenmakers, 2012, for a discussion). Failures to replicate the results of previously published studies have always been a part of the scientific literature (including in psychology), but the increasing number of such failures that appeared in the wake of the reproducibility crisis was the source of consternation for many researchers.

Zwaan and Pecher (2012) made an early effort to assess the reproducibility of studies that explore embodied approaches to language comprehension. They replicated six studies: Stanfield and Zwaan's (2001) two experiments examining whether comprehenders simulate the orientation of objects described in a sentence (e.g., in ***The pencil is in the cup***, the pencil would be oriented vertically), Zwaan et al. (2002) two experiments examining whether comprehenders simulate the shape of objects described in a sentence (e.g., in ***The eagle is in the sky***, the eagle would have its wings outstretched), and Connell's (2005, 2007) experiments asking whether comprehenders simulate the color of objects described in a sentence (e.g., in ***The steak was uncooked***, the steak should have a reddish color). Zwaan and Pecher (2012) found consistent evidence for mental simulation in their replication efforts, as each experiment showed a reliable effect of the content of the sentences on participants' responses to the pictures of the objects described in the sentences. Interestingly, whereas their effects replicated the patterns seen in Stanfield and Zwaan (2001) and Zwaan et al. (2002), their results showed the opposite pattern from the results

of Connell (2005, 2007). Where Connell (2005, 2007) showed that participants were faster to respond to pictures of objects where their color matched the way the object was described in the sentence (e.g., an uncooked steak is reddish, and leaves in a tree are green), Zwaan and Pecher (2012) found the opposite pattern (slower responses when the color of the picture matched the content of the sentence). Zwaan and Pecher (2012) did not have a definitive explanation for the discrepancy between their results and Connell's (2005, 2007), but they speculate that the inconsistency of the color effect might be due to the fact that color is not equally action-relevant for all stimuli.

Zwaan and Pecher (2012) successfully replicated Zwaan and colleagues' (Stanfield & Zwaan, 2001; Zwaan et al., 2002) reports that perceptual representations of the shape and orientation of objects are represented during language comprehension. Rommers et al. (2013), however, reported a series of experiments in which they failed to observe the previously reported effects. They suggested that perceptual representations may not be routinely generated during the comprehension process (though see Zwaan, 2014, for a rebuttal).

More recently, the replicability of Glenberg and Kaschak's (2002) Action-sentence Compatibility Effect (ACE) has been called into question. The ACE is observed in experiments where participants make motor responses while judging the sensibility of sentences about action. Glenberg and Kaschak (2002) presented participants with sentences describing action toward them (***Julie gave you a pencil***, where the pencil is coming toward you) or action away from them (***You gave Julie the pencil***, where the pencil is going away from you). Participants responded to the sentences using a response set-up similar to that shown in Fig. 27.1. Participants held down the START button in order to read the sentences. Then, to make a response to indicate that the sentence was sensible (or not), the participant released the START button and pressed either the button closest to their body (a response ***toward*** the participant) or the button farthest from their body (a response ***away*** from the participant). The ACE is the finding that participants generate a motor response more quickly when the direction of the action depicted in the sentence matches the direction of the action needed for the motor response.

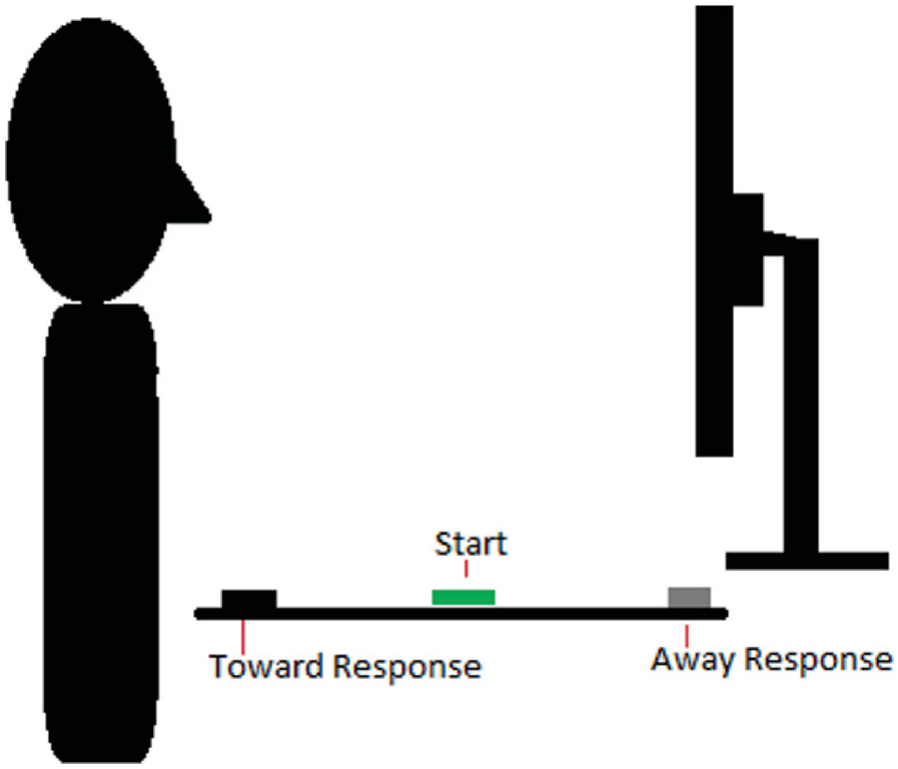


Fig. 27.1 Example set-up for an experiment aimed at testing the action-sentence compatibility effect

Papesh (2015) reported a series of experiments in which she failed to find evidence for the ACE. Many of her experiments contained features (such as visual displays on the computer screen where participants were reading the sentences) that may have prevented the observation of an ACE, but she also presented two direct replications of Glenberg and Kaschak's (2002) paradigm that failed to show any evidence for the effect. Morey et al. (under review) followed up on Papesh's (2015) observation by conducting an 18-lab, pre-registered replication of the ACE. They also found no evidence for the ACE.

Attempts to replicate findings that support embodied theories of language comprehension have produced some successes and some failures. We do not presently have definitive answers about what distinguishes the more reproducible effects from those that have been shown not to replicate. Nonetheless, in the next sections of the chapter, we offer some thoughts on the role that theoretical and measurement-related issues might play in shaping the reproducibility of effects in this area of the literature.

Theoretical Issues

We begin our discussion of the replicability of embodiment-related studies of language comprehension by considering the role of theory in the reproducibility crisis. Compared to issues surrounding experimental replications and research methodology, theoretical issues have received relatively little attention in the reproducibility crisis. Nonetheless, several commentators have pointed out the importance of theory as a root cause of the issues that have been observed with replications of published findings (e.g., Klein, 2014; Wilson, 2013a, b). A common theme for these commentators is the general lack of specificity in many psychological theories.

Embodied theories of language comprehension typically rest on a broad notion of priming or facilitation. Stanfield and Zwaan (2001) demonstrate that participants are faster to respond to pictures (e.g., a pencil oriented vertically) that depict an object in a way that is consistent with how that object was described in a preceding sentence (***The pencil is in the cup***). In other words, the perceptual representation of the pencil generated while reading the sentence primes the response to the picture. Similarly, Glenberg and Kaschak (2002) demonstrate that participants are faster to generate motor responses when the direction of the response is the same as the direction of the action in the sentence (e.g., an ***away*** response to sentences depicting ***away*** action, such as ***You gave Julie the pen***). In other words, the motor representation generated while reading the sentence primes the preparation and execution of the motor response. Many of the studies showing behavioral evidence for perceptual or motor representations being used in language comprehension follow the same basic logic: the content of the sentence generates perceptual or motor representation along some dimension (shape, color, direction), and these representations prime (or, interfere with) perceptual or motor processing (e.g., Meteyard et al., 2007; Ulrich et al., 2012). Although this theoretical approach typifies much of the literature on the embodiment of language comprehension, in what follows we will focus on theoretical issues in the context of understanding the ACE.

A priming-based approach to the ACE is consistent with the general idea of embodied cognition. Language is understood through its grounding in systems of perception and action planning, and language

about action elicits neural activity similar to the activity that would arise when actually moving in the world (e.g., Hauk et al., 2004). The elicitation of activity in the motor system via sentence comprehension is the putative vehicle for priming the motor response that participants are required to make. The priming-based approach is a simple and straightforward explanation for the ACE. Nonetheless, it is clear that explanations of this sort gloss over a number of important details. What exactly is primed? How does the priming work? How long does the motor activity elicited during language comprehension last? What strategies do participants use when reading and responding to these sentences? Is motor activity always elicited by sentence processing? How does the repetition of the same sentence structure across the experiment affect the comprehension process? Thus, although the priming account offers a simple and intuitive explanation for the ACE, it glosses over many of the issues that would be necessary to fully understand the participants' behavior in this task.

It is fair to point out that many of the questions raised above are empirical questions that could be resolved with further research. With regard to timing, for example, subsequent research found that motor priming tended to occur when the participant knew the nature of the response action to be performed during the processing of the sentence (Borreggine & Kaschak, 2006), and when the motor act coincided with the processing of the action verb in the sentence (Zwaan & Taylor, 2006). It was also found that the direction of the motor effect (priming or interference) depended on the exact temporal position of the motor response relative to the presentation of the action verb in the sentence (de Vega et al., 2013). Thus, although questions surrounding the nature of motor priming during sentence comprehension are empirical questions and can be resolved through further data collection (as seen here), it is important to note that the priming-based account does not provide concrete guidance for what researchers might expect to find as they pursue this empirical work. For example, there does not appear to be anything in the initial accounts of the ACE that would suggest a time-based pattern of motor facilitation and interference as later found by de Vega et al. (2013).

The earliest attempts to conduct an empirical investigation of embodied approaches to language comprehension, as exemplified by

the developing study of the ACE and related effects, were exploratory by necessity. Embodied theories were not sufficiently developed to generate predictions explicit enough to guide the development of a research program, and the extant literature in language comprehension did not make enough contact with the concerns of embodiment to allow the theoretical development to occur. The fact that the earliest embodiment research was exploratory is not problematic in and of itself. Exploratory research can be a useful way to establish an empirical basis from which theories can be developed. Of course, the success of this enterprise depends on the extent to which the problem space surrounding the research questions at hand is explored in a useful and systematic way. A look at the development of the literature on motor compatibility effects in comprehension shows that this was only partly the case.

Research into motor compatibility effects largely began with Glenberg and Kaschak's (2002) report of the ACE. Borreggine and Kaschak (2006) and Zwaan and Taylor (2006) reported further demonstrations of the ACE or ACE-like effects, but these both differed from the original paradigm in potentially important ways. Whereas the original study involved reading sentences and making a yes/no sensibility judgment on each item, Borreggine and Kaschak (2006) used auditory sentence presentation and a go/no-go response task (only responding to sensible sentences). Zwaan and Taylor (2006) employed a reading task, but changed the response modality (rotating a knob to make responses in the task, rather than toward-away actions). In addition, whereas most of the items in Glenberg and Kaschak (2002) and Borreggine and Kaschak (2006) were dative structures (***Julie gave the pen to you***), Zwaan and Taylor hid their critical items under a broader range of filler items. Bub et al. (2008) subsequently examined the elicitation of motor representations in the processing of words (specifically, object names), and did so using a response apparatus that allowed participants to make a range of motor responses (e.g., a pinching grasp; poking an object; and so on). Compared to the original demonstrations of the ACE, then, the linguistic stimuli, the nature of the motor responses, and the amount of training the participants required in order to do the task (participants in Bub et al.,'s 2008 study needed to go through training trials to ensure

that they produced the motor responses properly when cued) were all different. Explorations within these individual paradigms led to a richer understanding of some elements of the interplay between motor processing and language comprehension (e.g., Bub and Masson's elegant series of studies on the motor activity elicited by nouns; Masson et al., 2008a, b), but did not give rise to a more general theory of embodied language processing.

The set of studies described above highlight both the good and bad of the developing research program on embodied approaches to language comprehension. One positive aspect of this work is that, motor compatibility effects were seen with different kinds of linguistic stimuli (sentences about action toward and away from the body in Glenberg & Kaschak, 2002; sentences about rotating objects in Zwaan & Taylor, 2006; nouns in Bub et al., 2008), different kinds of motor responses (action toward or away from the body in Glenberg & Kaschak, 2002; rotating a response knob in Zwaan & Taylor, 2006; executing a variety of simple motor responses in Bub et al., 2008), and different presentation formats for the language (written language in Glenberg & Kaschak, 2002; spoken language in Borreggine & Kaschak, 2006; word-by-word sentence reading in Zwaan & Taylor, 2006; single words in Bub et al., 2008). The work, therefore, provided empirical support for the general claim that comprehending action-related language elicited motor activity. A negative aspect of this work is that so many task parameters changed between experiments that it was somewhat difficult to discern what factors were more or less important in driving the motor compatibility effects. For example, Glenberg and Kaschak (2002) and Zwaan and Taylor (2006) employed the repeated execution of the same basic motor response in their tasks, whereas Bub et al. (2008) used a wider variety of motor responses, and also had more explicit training on the execution of the motor responses. Does it matter how much variety there is in the motor responses, and whether there is training on the motor responses (which may highlight the motor aspects of the task)? Given that these variables are not systematically explored across experiments and lab groups, it is hard to tell.

The lack of a developed embodied theory of language comprehension led to a breadth-first approach to experimentation.

Because the embodied approach largely rested on the broad claim that language processing should interact with motor processing (or, in some cases, perceptual processing; e.g., Meteyard et al., 2007; Stanfield & Zwaan, 2001), the easiest route forward was to test the broad claim in a range of different paradigms in order to find cases where language did or did not interact with motor processes. Nonetheless, the amount of change in the linguistic stimuli, participant responses, and experimental design across studies created a situation where the individual paradigms showing embodiment-related compatibility effects were themselves not well understood. That is, because researchers explored conceptual replications of the motor compatibility effect (i.e., showing the basic effect, but in different kinds of experiments) rather than drilling down with more direct replications of the original findings, the development of an explicit theory of the role of the motor system in the comprehension process was hindered because it was hard to know which differences across studies produced important changes in the observed patterns of behavior. Consequently, when failures to replicate some of these findings arose in subsequent research (e.g., Morey et al., under review; Papesh, 2015), it was not immediately clear what to make of the failures, and where to begin looking for the factors that might determine when the target effects arise (see Wilson, 2013a, b, for similar points).

We have argued here that the lack of a well-articulated embodied theory of language comprehension has a) led to the development of a research program that is breadth-first and b) resulted in a collection of research findings that are consistent with the broad claim that language processing should interact with motor processing (or perceptual processing), but have not facilitated the development of a richer embodied theory of language processing. As Wilson (2013a, b) has argued, this state of affairs contributes to issues with reproducibility of research findings in part because researchers do not have a full understanding of why they observe the effects that they do, and what elements of the research paradigm are responsible for driving the effects. We have discussed this issue as a problem with research into embodied theories of language comprehension, but it is clear that the issues apply more broadly across psychology. For

example, the development of an embodied approach to language comprehension might have been facilitated by the existence of rich, detailed theories of language comprehension that capture the nature of the processing and representations involved as the comprehension process unfolds. As most theories of comprehension are typically pitched at handling one particular element of the comprehension problem (e.g., the role of frequency-based information in sentence comprehension, as in MacDonald et al., 1994; discourse processing, as in Kintsch, 1988), they did not provide the guidance needed to develop a detailed embodied account of language processing. For example, although the idea of motor activity playing a role in language comprehension could be accommodated within the framework of a constraint-based approach to sentence comprehension (e.g., MacDonald et al., 1994) or a theory of discourse processing (e.g., Kintsch, 1988), the extant theories do not provide a clear speciﬁcation of how that accommodation would need to work.

It might seem that we have identiﬁed a hopelessly circular conundrum for research on embodied approaches to language comprehension: good, precise theories are needed to guide solid, productive research programs, but good, precise theories of embodied language processing are lacking because of the nature of the research that has been done (which itself is guided by an overly-general theory). Things might appear to be even worse when observing that some of the empirical underpinnings of the embodied approach (e.g., the ACE) have turned out not to be replicable in the lab (Morey et al., under review; Papesh, 2015). Nonetheless, we can see a couple of paths out of this conundrum. First, we think it is worthwhile to acknowledge that more exploratory work needs to be done in this area of research, and to acknowledge that the work is exploratory (rather than trying to shoe-horn each new ﬁnding into ad hoc theories constructed to explain this or that ﬁnding). As the exploratory phase of this research program continues, replication failures should be expected to occur as researchers slowly feel their way toward the factors that affect the interplay between language processing and motor processing (see Wilson, 2013a, b, for a similar point about research into social priming). Importantly, by acknowledging the exploratory nature of this work, it will be possible to interpret new research ﬁndings within a

more useful perspective. Rather than thinking about a finding (e.g., the ACE) as a definitive demonstration of embodiment in language processing, the findings might be treated as more provisional pending further exploration.

Wilson and Golonka (2013) identify a second path out of our conundrum, arguing for a more task-oriented approach to research in embodiment. They suggest that by examining the task before the participant (what are the participants asked to do?), the information that is potentially available to perform the task, and the ways that the information might be exploited to support task performance, researchers can develop a rich and detailed understanding of their participants' behavior. Such a research program would fit with our call for more exploratory research into embodiment. It would also provide a blueprint for researchers to follow as they conduct this exploration.

As we continue to learn more about the reproducibility of different findings in the embodiment literature, it is our sense that the field would do well to consider theoretical issues such as the ones raised here. Lack of a good theoretical understanding of the tasks at hand certainly contributes to issues with reproducibility (as discussed here). In the next section, we consider how measurement issues also contribute to the reproducibility of embodiment research findings.

Measurement Issues

Theory is important for guiding the embodiment research program. Just as important as having good, explicit theories to guide our research programs is having appropriate measurement of the behaviors of interest. In this section of the chapter, we discuss some issues related to the measurement of constructs in the embodiment literature, and the implications that this has for reproducibility.

We begin by returning to the research paradigm used to examine the ACE. Participants have to read a series of sentences and need to execute motor responses in order to indicate whether the sentence is sensible or not. Evidence for the ACE is observed when there is a statistical interaction between the direction of the action depicted in the sentence and the direction of the action required to respond to the sentence (Morey et al., under review). It is presumed that the

interaction reflects the interplay of motor information elicited by the processing of the sentence, and motor activity required to execute the motor response. In other words, the magnitude of the interaction can be taken as an index for the extent to which the motor activity that arises during language processing affects the operation of the motor system, a key prediction of the embodied approach to language processing. This is a straightforward interpretation of the ACE (and the behavior measured in this task), but it misses key elements of what exactly the task may be indexing.

It has long been known that comprehenders can tackle the problem of interpreting language in different ways. As one example, Ferreira (2003) describes what she termed the "good enough" approach to comprehension—participants use a set of quick-and-dirty heuristics to decode the meaning of the language they are processing to create a "good enough" interpretation of the linguistic input rather than constructing a rich interpretation of the input. The idea of the interpretation being "good enough" is defined as relative to the context in which the language is processed, with the comprehender doing just enough work to get by given the constraints of the task. The "good enough" strategy bears some similarity to the minimalist approach discussed by McKoon and Ratcliff (1992), which proposes that comprehenders only draw inferences that are minimally necessary to make the linguistic input make sense. The "good enough" and minimalist accounts contrast with the constructivist approach of Graesser et al. (1994), which presumes that readers construct richer representations of the linguistic input that they are processing. Thus, whereas language users may default to a shallow, "good enough" strategy for interpreting language, it is possible for them to attend more closely to the linguistic input and to develop richer, more detailed representations of what is described in the linguistic input.

The idea that language users may use "good enough" comprehension strategies in some contexts, and richer strategies in other contexts, is echoed in Barsalou et al. (2008) Language and Situated Simulation (LASS) approach. Barsalou et al. (2008) argue that conceptual processing relies on two related systems. The first is a system that has representations of linguistic form. These forms are accessible early in processing, and can be rapidly used to perform basic

tasks (such as deciding whether a string of letters is a word or not). The second (slower) system is responsible for generating situated simulations of the content of the language (e.g., simulating the image and sound of a dog upon hearing the phrase, ***the barking dog***). Barsalou et al. (2008) suggest that whereas the linguistic system can be used to perform many tasks (such as traditional psycholinguistic tasks like lexical decisions), much of conceptual and linguistic meaning resides in the simulation system. Within the context of the present discussion, it might be said that the linguistic system may largely suffice when "good enough" processing is in order, but the situated simulation system is necessary for deeper levels of comprehension.

The question of how richly comprehenders are representing their linguistic input is of relevance to the reproducibility of embodiment research. Rommers et al. (2013) propose that the perceptual effects reported by Stanfield and Zwaan (2001) and Zwaan et al. (2002) may be driven in part by an imagery strategy. If participants generate mental imagery while processing the sentence (e.g., they generate imagery of an eagle in the sky, or a pencil standing in a cup), they will show a stronger effect of the sentence content on responding to the picture presented after the offset of the sentence than if they do not generate such imagery. Thus, the magnitude of the effect observed in a given experiment using this paradigm may index (in part) the number of participants in the study who use the imagery strategy to perform the task. Beyond the issue of whether or not participants are generating imagery to perform the sentence-picture verification task, there is the question of how deeply participants need to process the sentences in order to successfully complete the task. For example, the participant may realize that all they need to do to make the task decision (does the picture relate to the sentence you just read?) is to note the object named in the sentence and see if that object is in the picture. Upon reading ***The eagle is in the sky***, the participant just needs to remember ***eagle*** and see if this matches the picture. The content of the rest of the sentence would not be necessary to perform the task. Participants using this sort of strategy might fail to show the predicted effect. We have some indication that this might be the case. When the first author was in graduate school, he and his advisor attempted to replicate Stanfield and Zwaan's (2001) basic effect. We found that we

could only observe the effect in cases where we included comprehension questions in the task, presumably because the occasional comprehension question forced the reader to attend to the content of the language more carefully (see Zwaan, 2014, for a discussion of this point). The effects found in experiments designed to elicit the ACE also seem to be affected by participant strategies. Papesh (personal communication, June 2, 2020) reports an experiment in which she manipulated whether or not participants were made aware of the possibility that their motor responses might coincide with (or conflict with) the action of the sentence to which they were responding. Her results show that the ACE is present when participants were made aware of the possibility of a motor compatibility effect, and that the ACE is not observed when the participants were not informed about the possibility of a motor compatibility effect.

Consistent with other discussions in the literature (e.g., Ferreira, 2003; Foertsch & Gernsbacher, 1994), it appears that participants in experiments exploring the interplay between perception, action, and language may choose different strategies for completing the task before them, and that the nature of these strategies may affect the patterns of behavior that are observed. Specifically, the observations at hand seem to suggest that adopting a strategy related to deeper comprehension (e.g., generating imagery based on the linguistic input) may lead to stronger demonstrations of the activity of perceptual and motor systems during language processing. While plausible, this proposal has not been extensively explored in the literature, and further work will be required to confirm the nature of the strategies that participants use in these research paradigms, and the effects that these strategies can have on the effects seen in the data.

To get back to the issue of measurement, the preceding discussion suggests the possibility that behavior in tasks such as the ACE paradigm may not only be an index of the role of perceptual and motor representations in language processing. This point may not be controversial, but it highlights the need to understand what elements of the participants' behavior are driving task performance. The implications of these tasks for an embodied theory of language comprehension are much different if the results are found to be largely driven by participant strategy than if the results are found to be

independent of participant strategies. This point also relates back to our point about theory, the need to have explicit theories about what is happening as participants perform experimental tasks, and the need to embed these theories into the broader theoretical context that comes with a study of language comprehension processes in both "embodied" and "non-embodied" kinds of tasks.

In addition to questions about what our experimental tasks are measuring (embodied processes, participant strategies, or something else?), there are also questions about how well we are measuring our participants' task performance itself. Many of the effects reported in the embodied language comprehension literature are small. Within the paradigms that we have discussed throughout this chapter, Morey et al. (in press) estimate that the effect size for the ACE is essentially zero, and Zwaan and Pecher (2012) note that the effects in their replications of Stanfield and Zwaan (2001), Zwaan et al. (2002) and Connell (2005, 2007) are in the range that is typically considered to be small (all Cohen's ***d*** values < 0.25, where a ***d*** of 0.2 is considered a small effect). Given that embodied effects are typically small, good measurement practices would appear to be necessary in order to reliably observe the effects across studies.

Rouder, Kumar, and Haaf (2019) present an analysis of measurement in inhibitory control tasks such as the Stroop and Flanker tasks. Rouder et al. (2019) note that whereas the Stroop and Flanker tasks are both putative measures of inhibitory control (and have been used as such in the literature), they do not correlate with each other, and they do not show strong test–retest reliability. Rouder et al. (2019) argue that the design of the typical Stroop or Flanker task does not allow for good measurement of the inhibitory control construct largely because the comparatively small number of trials used in the standard experiment (in this case, "small number" refers to around 100 observations per condition) means that trial-level noise contributes a good deal to the measurement error in the task, attenuating correlations between tasks and the reliability of the tasks themselves. In their view, the best way to improve measurement in these tasks is to increase the number of trials in the experiment. Rouder et al. (2019) discuss the issue in the context of improving tasks such as Stroop and Flanker for the purpose of measuring individual

differences, but we believe that their analysis has implications for researchers studying embodied effects in language comprehension.

Embodied language comprehension tasks are typically not used as individual difference measures, and issues such as the correlations between tasks, and the reliability of the tasks across time, have not been considered in the literature. Nevertheless, Rouder et al.'s (2019) larger issue about accurately measuring the behaviors of interest in these experiments still applies. There are a couple of issues to address here. First, there is the question of assessing individual variation in the magnitude of the embodied effects that are observed (e.g., the ACE, or the "match" effect reported by Zwaan et al., 2002). An examination of the data from experiments such as these often reveals a range of effects across individual participants: some show the predicted effect, some show no effect, and some may even show a reversed effect. Haaf and Rouder (2019) note such a state of affairs might reflect a case where all participants have a true positive effect (despite the observed variation in the participant-level effects) or where some participants show a true effect and others do not. Distinguishing between these two possibilities has implications for our understanding of the embodied effects that are observed. For example, if some participants show an effect and others do not, it might imply the presence of an important individual difference in task performance that needs to be explained (e.g., differences in participant strategies, or in reading skills). Such differences might have implications for the replicability of particular findings.

Just as there can be concerns about individual differences across participants, there can also be concerns about individual variation across items. Even in cases where items are normed prior to inclusion in an experiment, it is still possible that individual items will vary in the degree to which they show the target effect. (In our experience with these research paradigms, such variability is almost always present.) In the same way, that person-level variation represents a key type of variability that any theory should explain, so item-level variability is something that needs to be explained. A well-specified comprehension theory should be able to account for this type of variability. More broadly, gaining an understanding of item-level variability might be just as important to understand why research findings are

reproducible (or not) as participant-level variability is. Finally, as Rouder et al. (2019) discuss, being able to estimate trial-level variability (independent of participant- and item-level variability) is also crucial for understanding the effects under study.

It is clear from the analysis presented by Rouder et al. (2019) that much of the research in the embodiment program has been poorly designed from the perspective of getting a clear sense of the magnitude of the effect under study, the participant-level variability in the effect, and the item-level variability in the effect. A good number of the studies in the published literature have sample sizes under 100, and typically have fewer than 50 critical trials spread across conditions. These numbers are well under what Rouder et al. (2019) recommend for experiments that are much simpler in terms of task demands and item-level variability than the traditional "embodiment" experiment. To the extent that researchers in this field are going to assess the replicability of embodied language processing findings, it strikes us that it will be particularly important to design studies to adequately measure the different sorts of variability that might affect task performance (i.e., studies with many participants and trials) to the extent that it is possible to do so. In cases where this is not possible (e.g., in Connell's, 2005, 2007, experiments, it may not be possible to generate a large number of individual color-diagnostic items), the results (and potential replicability) of the studies should be qualified appropriately.

The Future

In this chapter, we have considered the literature on embodiment in language comprehension through the lens of the reproducibility crisis. Though there have been comparatively few replication efforts within this area of study, the efforts that have been made have demonstrated a mixture of successful and unsuccessful replications. The mixed results of the replication efforts suggest that a careful examination of the robustness of this literature may be in order.

As researchers move forward assessing the robustness of the embodiment literature, it will be important to consider the potential factors that might contribute both to unreliable findings within certain

paradigms and to reliable findings within others. Many discussions of the reproducibility crisis have focused on the role that statistical decision-making and questionable research practices might play in generating findings that are not reproducible. Here, we focused on a different set of issues that have received comparatively less focus in the reproducibility crisis—theoretical issues and issues related to measurement. We argued that embodied theories of language comprehension are generally too under-specified to allow for a detailed understanding of the effects that are observed. We further argued that most if not all of the experiments in this literature are designed such that they have insufficient numbers of participants and items to accurately assess the magnitude of the overall effects and sources of individual variation present in the studies. It is our sense that both of these factors will conspire to produce results of uncertain reliability.

We have already identified potential avenues for improvement in the embodiment literature: developing more explicit theories where possible, and acknowledging the exploratory nature of research where such theories do not exist; carefully examining the possibility that participant strategies may play a role in driving "embodiment" effects; and where possible designing experiments that maximize the possibility of measuring different elements of task performance. To these possibilities, we can add that researchers should consider adopting open science practices such as data sharing and pre-registration of studies where it is feasible to do so.

We are aware that this chapter has a somewhat pessimistic tone, arguing that embodied theories of language processing are too broad to be of specific use in understanding our research findings, and that much of the literature consists of experiments that do not have the measurement properties necessary to gain a firm understanding of what has been observed. Though the existing literature in this area of research is less than ideal in some ways, it is our sense that this is to be expected given the relative newness of the embodied approach to language, and the current state of affairs in much of psychology (where the theoretical and measurement issues highlighted in this chapter are just as applicable). It is our hope that discussing these issues will lead to a better understanding of what can be taken from the extant

literature, and what can be done to improve the research conducted as we move forward. Even if the previous research efforts turn out not to have been wholly successful in growing our understanding of the role of systems of perception and action planning in the comprehension process, they will have served a useful purpose to the extent that they help us understand the nature of the problem space that needs to be navigated as we build an embodied theory of language use.

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